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The first three of the above papers were presented at a symposium on "The Effects of Chemical Control of Forest Insects on Fish Stocks," held by the Committee on Biological Investigations of the Fisheries Research Board of Canada in Ottawa, January, 1958. A fourth paper submitted, "Effects of Spruce Budworm Control on Stream Insects in New Brunswick," by Dr. F. P. Ide, Department of Zoology, University of Toronto, was published in the Transactions of the American Fisheries Society, Vol. 86, 1956, pp. 208-219.

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Minister of Fisheries

Aerial Chemical Control of Forest Insects with Reference to the Canadian Situation

by

F. E. Webb

Science Service, Federal Department of Agriculture, Fredericton, N.B.

The Forest Insect Problem

The value of the Canadian forestry resource is no more impressive than are the problems of protecting it. Of the various factors responsible for forest losses other than man, none exerts a more consistent drain on timber inventories than insect damage (5). A generalization about Canadian forests is that they are chiefly of the Boreal type. This means that huge areas are covered by relatively uniform stands, often of the same age-class, comprised of relatively few tree species and usually dominated by one or two of the conifers (7). This type is uniquely valuable as a source of pulp and paper, but is a relatively unstable ecological association and successional changes are commonly sudden and violent. On the other hand, the cataclysmic natural events that have played a part for centuries in the periodic replacement of successive crops—chiefly fire, blowdown, and insect outbreaks—generally tend to perpetuate the kind of forest that they ravage. Aspen, pine, and spruce are typical post-fire types; in eastern Canada conditions for the reproduction and growth of the ubiquitous balsam fir are never better than following the destruction of mature stands of the same species by the spruce budworm (6). These natural catastrophes played a dynamic role in succession before man began to exploit the forest but only since the rapid development of the Pulp and Paper Industry, with its full use of the forest growth, have they become serious economic problems.

Some of the current problems with native insects arise partly from man's interference. Selective cutting of certain species or vigour classes may create a condition of higher susceptibility to insect and disease attack in the residual crop. From the point of view of the forest manager and the silviculturist, clear-cutting for pulpwood is often sound practice, yet it is the opinion of some that this is encouraging a higher proportion of balsam fir reproduction and intensifying the threat from the spruce budworm (16). The presence of large quantities of logging slash and logging injuries to residual trees sometimes increase the incidence of bark beetle and borer attack in surrounding uncut stands. Equally serious, numbers of foreign insects have been introduced over the years and some of these now pose major problems. In short, insect problems and the need for protection have tended to increase rapidly with increased accessibility and exploitation of our forests (13, 14).

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*Contribution No. 463, Division of Forest Biology, Science Service, Department of Agriculture, Ottawa, Canada.

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The Place of Aerial Spraying in Forest Insect Control

Most forest entomologists subscribe to the philosophy that the ideal in forest insect control is prevention rather than cure. The creation of resistant forests, however, takes time and can only keep pace with the development of forest management. It must be based on intensive ecological research translated into practical economic silviculture. Such research is being undertaken and forest management is becoming more intensive but the completely resistant forest is likely to remain an ideal, at least for many years to come (2).

Biological control by the manipulation of parasites, predators, or disease organisms has been successful in some cases of introduced pests. The possibilities of their use against such native pests as the spruce budworm have been and are still being studied, but as yet without positive results.

Meanwhile direct measures must be applied if severe outbreaks are to be prevented from seriously reducing the supply of raw material of the forest industries and at the same time disrupting management plans on which sustained yield and the ultimate production of more resistant forests depend. If, for instance, the spruce budworm kills large areas of forest, the succeeding stand will be even-aged and of high balsam content—difficult to manage for sustained yield, and highly susceptible to future outbreaks (12).

The discovery of DDT and the development of aerial methods of application have made the use of insecticides against a number of forest insects practicable. This, combined with the increasing importance of the full use of our forest growth, explains the number of large-scale operations since the second World War (3).

Forest entomologists are fully aware of certain limitations and possible dangers in chemical methods of control. They have always been concerned with the population dynamics involved and have sought the aid of other workers in attempts to determine effects on fish and wildlife. However, when spraying presents the only means of protecting a forest from serious loss it becomes necessary to use it (1). At the same time this does not imply prolonged or continuous use of insecticides analogous to agricultural practices. In forestry it is not necessary to maintain insect populations at as low levels as in agriculture and large-scale use of aerial spraying in Canada has been limited to the prevention of tree mortality. These operations are being studied as closely as possible to determine their long-term effects on the population dynamics of the pest and associated insects (18).

Aerial spraying operations may range in size from a few hundred acres as in the case of plots, or plantations, to several thousands of square miles as against the spruce budworm. In most cases they involve defoliating insects for which dosages of 1 lb. DDT/acre or less have become more or less standard. Important adverse effects against other forms of life have seldom been reported from small operations using dosages of this order, and recovery is generally rapid (4, 15). Serious effects are more likely from blanket coverage of extensive areas, particularly when treatment is repeated. For purposes of the present discussion, therefore, it will suffice to consider only the larger type of operations involving extensive forest areas. These are listed for Canada to date in Table 1. Since the spruce budworm has been far and away the most serious

problem to date in Canada and because of my own experience with it, I propose in the following sections to refer in particular to the recent large-scale operations in eastern Canada.

Table 1

History of Large-Scale Forest Spraying Operations in Canada. DDT-Oil Formulations Used in All Cases

Insect	Year	Province	Dose: DDT	Acres	Sq. mi.
Western hemlock looper	1946	B.C.	1 lb./acre	12,000	19
False hemlock looper	1948	B.C.	1 lb./acre	11,000	17
Black-headed budworm	1957	B.C.	1 lb./acre	156,000	240
Spruce budworm	1945	Ont.	1 lb./acre	64,000	100
	1946	Ont.	2 lb./acre	29,000	45
	1952	N.B.	1 lb./acre	186,000	290
	1953	N.B.	*½ lb./acre	1,800,000	2,800
	1954	N.B. and Que.	"	1,500,000	2,300
	1955	N.B. and Que.	"	2,200,000	3,400
	1956	N.B. and Que.	"	2,400,000	3,750
	1957	N.B. and Que.	"	6,500,000	10,200

*Approximately 25 per cent of 1953 area treated twice.

Aerial Spraying with Particular Reference to the Spruce Budworm

History of Outbreaks

Evidence can be found in forests of northeastern North America of outbreaks dating back over 150 years. Intervals between them have varied from about 70 years in northwestern Ontario to 35-40 years in New Brunswick. Severe infestations have been reported somewhere in eastern Canada practically every year for at least the last 40 years and an estimate has been made that between 1909 and 1946 outbreaks had killed some 250 million cords of balsam fir and spruce (5). Particularly widespread and severe outbreaks occurred between about 1909 and 1920 and from the late 1930's until the present time. In both these periods the outbreaks have shown a tendency to shift from west to east, beginning in northern Ontario and ending in the Atlantic regions of New Brunswick, Nova Scotia, and the Lower St. Lawrence-Gaspé regions of Quebec. At the present time outbreaks are at a relatively low ebb over much of Ontario and Quebec north of the St. Lawrence and are most severe in the Atlantic Maritime region. At the same time, however, trees are still dying from the attacks of the last 10 to 15 years over thousands of square miles in Ontario and Quebec and persistent pockets of infestation still occur in western Ontario that have been under more or less continuous attack for 15 years or longer.[1]

In New Brunswick the current outbreak first became severe in 1949 and some idea of the rate of spread is shown in Table 2. It is also illustrated in Figures 1-3 showing the areas involved in three representative years, 1952, 1954, and 1957 respectively. It

[1]*Annual Reports, Forest Insect Survey, Forest Biology Division, Science Service, Canada, Dept. of Agriculture, 1937* et seq.

Table 2

Areas of Severe Attack by Spruce Budworm in New Brunswick and Areas Treated by Aerial Spraying

Year	Areas—sq. mi.		% severely attacked area sprayed
	Severe attack	Sprayed	
1949	200	0	—
1950	400	0	—
1951	2,200	0	—
1952	5,000	300	6%
1953	11,000	2,800	25
1954	13,000	1,800	14
1955	13,000	1,800	14
1956	16,000	3,100	19
1957	20,000	8,100	40
1958	?	(3,900?)	

Percentage of N.B. areas sprayed once: 13.7
twice: 55.5
three times: 28.3
four times: 2.5

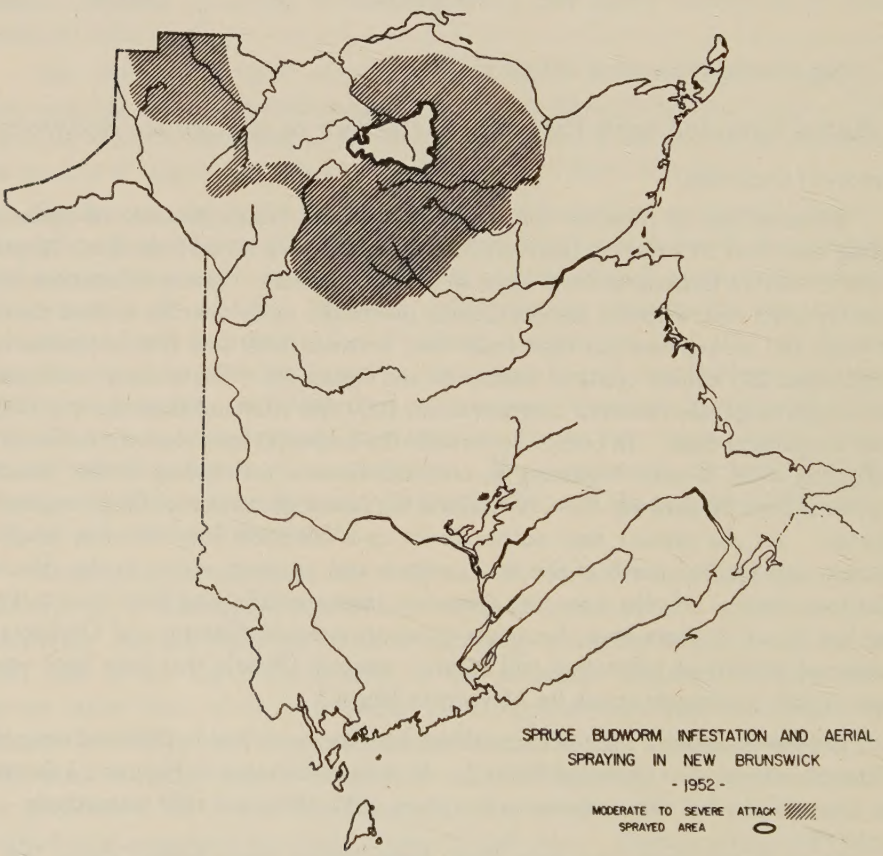

FIGURE 1

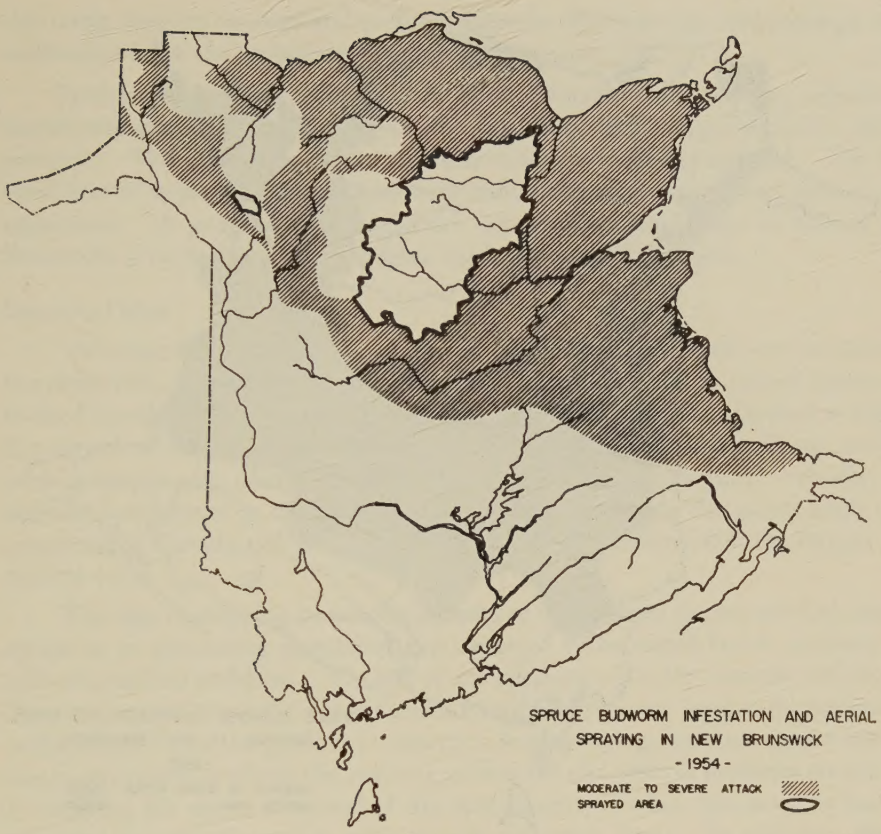

FIGURE 2

should be pointed out that the table and maps refer only to areas of severe attack and that there were also large areas of lighter attack in each of these years.

Brief History of the Aerial Method

The spruce budworm was not the first forest insect to be treated from the air, but it is of interest that 1957 was the 30th anniversary of the first spruce budworm aerial control project ever attempted. That was in Nova Scotia in 1927. The conclusion reached in those early years was that while dusting was a useful method against insects such as hemlock looper, it was not likely to be highly successful against the budworm until better insecticides and equipment were developed. The advent of DDT oil sprays during the War answered many of the problems and a good deal of work was done in the immediate post-war years in both Canada and the United States to develop suitable application equipment and techniques. In 1949, the first of a series of large-scale annual operations against the spruce budworm was carried out in the Douglas fir regions of Oregon and Washington and by 1955 these totalled nearly 4 million acres. Operations on a similar scale have been underway since 1953 in the Rocky Mountain regions from New Mexico to Idaho and Montana. The history of large-scale Canadian operations as summarized in Table 1 gives some idea of the relative importance of the spruce budworm problem as compared to other defoliators. The first budworm

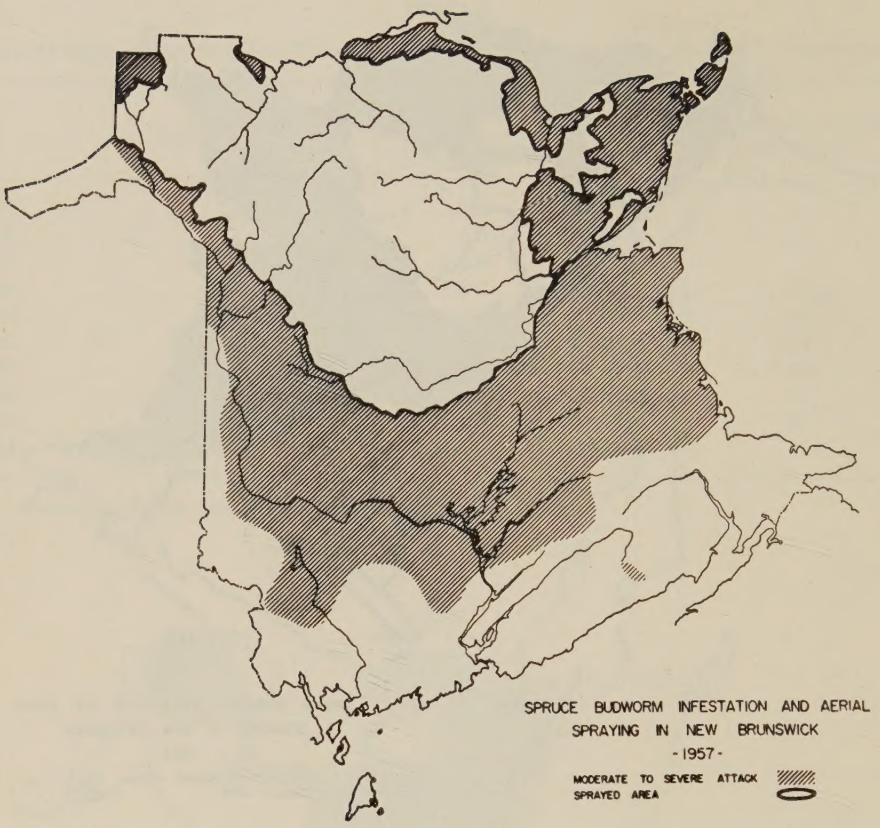

FIGURE 3

operations, totalling some 93,000 acres, were carried out in 1945 and 1946 in the Lake Nipigon area of Ontario (10). The largest operations of all, however, have been underway since 1952 in New Brunswick and since 1954 in adjacent areas of Quebec. These now total about 14.5 million acres including respraying. This is an acreage in excess of the land area of several European countries including Switzerland. All the more remarkable is the fact that nearly half this was sprayed in a single year, 1957—nearly 6.5 million acres in the two provinces. New Brunswick's share alone amounted to 5.2 million acres.

Organization and Direction of New Brunswick-Quebec Operations

The organization and direction of the New Brunswick operations is the responsibility of a provincial Crown Company, Forest Protection Ltd. Mr. B. W. Flieger is the Manager. Shares in the Company are held by the four leading pulp and paper Companies in the province and by the New Brunswick Department of Lands and Mines. Costs are shared equally by Canada, New Brunswick, and industry. The Division of Forest Biology has been closely associated with the project since its beginning and is responsible for various aspects of technical advice and assistance. These include timing the spraying, assessing immediate results, and estimating hazard from surveys of infestation and defoliation. A programme of long-term investigation is

also under way to discover and evaluate ultimate effects on the epidemiology of the budworm and on the growth and survival of the forest (18).[1]

Quebec operations are carried out by Quebec Forest Industries Assn. representing landowners and leaseholders. Costs are shared equally between industry and the province. The operations in the two provinces are closely integrated. The same aerial fleet is employed for both jobs using identical timing, dosage, and techniques of application. A programme of assessment and investigation similar to that in New Brunswick is carried out by the Quebec Laboratory of this Division.

Spraying Policy

The stage of an outbreak at which spraying is undertaken will vary according to the objectives. Some of the operations carried out in recent years against gypsy moth in the United States have treated very light infestations with the objective of limiting the spread of this new insect beyond an established barrier zone. These and some other examples are often referred to as "eradication programmes"—usually with dubious justification in the light of experience. Fortunately the gypsy moth is not important in Canada and there is yet no comparable problem from the foreign pests that do occur.

The idea of spraying incipient outbreaks of native pests to prevent their rise and spread is an interesting possibility that deserves to be tested but it involves some difficult practical problems. The foci of outbreaks are not easily detected early in their development in forests the size of Canada's and are often very large in themselves. It will seldom, if ever, be possible to organize a large spraying operation against the same insect generation in which the outbreak is detected and difficult problems are involved in mapping the extent of spread of the next generation when this must be based on extended surveys of eggs or other minute immature forms. In addition, effective control at relatively low populations is likely to call for larger dosages than the minimum required against heavy infestations of defoliators owing to the greater concealment of larvae in the denser foliage of undamaged trees.

The alternative to early spraying to control outbreak trends is to delay treatment until it is necessary to prevent tree damage. In dealing with the operations listed for Canada in Table 1 a consistent policy has been followed of recommending spraying only when a further year's defoliation would seriously threaten the life of trees. This is a conservative policy that avoids the uncertainties of spraying incipient outbreaks and gives natural control factors the best opportunity to exert a regulating effect before resorting to applied measures. However, it calls for a degree of judgement and a good knowledge of the ability of trees to withstand attack.

Techniques and Procedures

FORMULATIONS AND DOSAGE: DDT is the most commonly-used insecticide again forest insects and has been used on all the large-scale aerial operations in Canada. This is because of its low cost and high toxicity, particularly against free-living defoliators. Its chief effect is as a contact poison but this is reinforced by

[1]*Annual Summary Reports on these operations have been published in the following issues of the Bi-Monthly Progress Rept., Div. For. Biol., Dept. Agric. Canada. New Brunswick: 8(4); 10(1); 11(1); 12(2); 13(3). Quebec: 11(1); 12(1); 13(3).*

stomach and residual poisoning. The most commonly-recommended dosage against forest defoliators in North America is 1 lb. DDT per acre, usually in one U.S. gallon of oil solvent. Only once in Canada has this been exceeded on a large scale—in northwestern Ontario in 1946 (10). It was used in the first New Brunswick operation of 1952. Since 1953, however, practically all the New Brunswick-Quebec spraying has been done at half this dosage by doubling the average distance between adjacent flights of the spray planes. With good timing and with some drift it has been found to give results nearly as good as the heavier dosage, especially when applied against conditions of very heavy infestation. In effect it has permitted the treatment of nearly double the area at the same cost and using the same aerial fleet and facilities. These advantages are considered adequate to make up for the somewhat lower average percentage of control that is obtained and for the slightly less uniform coverage that is inevitable.

A limited amount of the New Brunswick spraying has involved two applications at the $\frac{1}{2}$-lb. dosage two to three weeks apart. The earlier application provides good foliage protection while a high percentage of kill is ensured by the later spraying. This technique is considered more effective than the single application at the 1-lb. dosage and is the safest way of ensuring good results in cases of extreme hazard or where the values at stake are particularly high.

SPRAY EQUIPMENT AND CALIBRATION: The most widely-used dispersal apparatus is the boom and nozzle type, fed under pressure from a tank in the airplane fuselage. The pressure and the nozzles are adjusted to give the appropriate rate of flow and the proper range of droplet sizes. The optimum droplet size is the minimum that will reach the trees before evaporation. Too-fine sprays drift excessively and reduce the average deposit. Coarse sprays are wasteful, give poorer coverage, and may be more hazardous to aquatic life.

FLYING PROCEDURE AND SPRAY COVERAGE: A wide variety of aircraft types have been used from the smallest single-engined planes to multi-engined transports and converted bombers. A helicopter was used for the 1948 operation against false hemlock looper in British Columbia but their use has not otherwise been common owing to excessive cost. Light conventional aircraft are generally preferred owing to their relatively low cost of operation, greater manoeuverability at low levels and their availability. The most widely-used type is the Stearman bi-plane converted from the World War II elementary trainer. It has been used exclusively in New Brunswick and Quebec except for one de Havilland Beaver used in 1952. The aerial fleet has varied from 20 planes in 1952 to 200 in 1957.

The procedure in most aerial spraying is to fly as close to the ground as is commensurate with safety and the problems of navigation. Forest spraying is commonly carried out at about 50 to 250 feet with the smaller airplane types depending mostly on topography. Pilots are assigned individual spray blocks of an average size of about 5,000 acres and coverage may be obtained by flying adjacent swaths from end to end over flat terrain or by "contouring" on slopes. In New Brunswick, the practice has been adopted of flying planes in pairs rather than singly. This has advantages in safety, simplifies the problems of supervision and control, and improves the chances of obtaining uniform coverage.

Good coverage depends largely on the skill of the pilot in low-level navigation. With the most precise flying possible, however, uniform coverage would be unlikely without drift. For that reason low wind velocities are often considered advantageous and experienced pilots are skilled in allowing for and taking advantage of drift. Experience has shown the necessity of isolating unsprayed check plots by at least one and preferably more miles from the nearest spray boundary and of spraying around such areas only with favourable winds. Although pilots are instructed to shut off the spray over open water, this seldom prevents some of the spray from entering streams and lakes. Water courses are some of the most easily-recognized topographical features and they very frequently form boundaries between spray blocks. For this reason coverage along some streams may average heavier than within the blocks.

TIMING APPLICATIONS: A good deal of the success of aerial spraying depends on the timing of applications. The objectives can be twofold: to achieve the maximum possible reduction of the insect population and to prevent defoliation. The first objective is best achieved by spraying when most of the feeding is completed and larval exposure is at a maximum; the second calls for early spraying, usually with some sacrifice of percentage of kill. The policy in New Brunswick and Quebec has been to achieve the best compromise by bracketing the optimum period as effectively as possible (17). With the spruce budworm this involves a period of about two weeks in a specific locality. Phenological differences within the areas under treatment vary as much as three weeks and advantage is taken of this to commence spraying in the more advanced southern areas and to shift operations farther north as conditions permit (19).

More precise timing than that described here for the spruce budworm would be difficult to put into practice owing to the uncertainties of weather and the exigencies of large-scale operations. However, where more leeway may be possible, as in small operations or against other pests, consideration should be given to the possibilities of adjusting timing to reduce adverse effects against parasites and predators and other forms of life that may be particularly vulnerable during some part of the spraying period (2).

ASSESSING RESULTS AND EVALUATING HAZARD: In most operations spray coverage is checked on the ground by means of test cards or plates that are set out to sample the deposit in representative locations. This technique was used in New Brunswick and Quebec in the first one or two years and it showed that good coverage of lethal deposits could be obtained over all types of terrain by good flying aided by drift. In the very large programmes that have followed, however, it has been necessary to place greater reliance on close aerial supervision of the spraying by inspection pilots. These men are experienced forest sprayers and they are also responsible for pre-flight briefing of spray pilots, and for judging the suitability of spraying weather. Ground assessment is still carried out on biological study areas and some use is being made of evidence of spray burn on hardwood and herbaceous foliage for extended spot checks.

Assessment of immediate biological results are necessary each year as a check on the efficacy of the toxicant and the effects of timing, weather, and techniques of application. Special problems are encountered in evaluating results and assessing hazard over very large areas such as those involved in New Brunswick and this has called for

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the development of suitable surveying and sampling methods. Aerial surveys have been used extensively every year to compare sprayed and unsprayed areas and to determine the boundaries of light, moderate, and severe attack throughout the Province. Large-scale ground surveys have been developed for two main purposes: (1) to measure immediate results of the spraying by comparing defoliation and post-spray budworm survival in sprayed and unsprayed areas, and (2) to measure egg populations of the next generation and combine this with the estimates of defoliation and damage for the purpose of gauging hazard. In both cases a system of sequential sampling has been developed that ensures the greatest economy of counting effort and takes the best advantage of limited time and staff.

Studies of ultimate results are a long-term proposition that should preferably consider the whole ecosystem and the New Brunswick-Quebec operations provide a unique opportunity to undertake such studies. In view of the aggressiveness of this insect and the huge areas of susceptible forest this is probably the severest test of chemical control that has ever been made. Intensive studies of the epidemiology of this insect and the possibilities of reducing its threat by forest management were already well underway in New Brunswick when spraying began, and these studies provided the best possible basis upon which to extend the investigation to the effects of spraying (12). Comparisons are being made of population trends in sprayed and unsprayed areas and these are being related to measurements of regulating factors. The effects of spraying on the growth and survival of the trees are under study and this is contributing annually to our knowledge of the ability of different host species to sustain attack. Extended observations are made each year for the purpose of detecting any unusual occurrence of other pests and gross measurements are being made of the effects of spraying on other insects—both terrestrial and aquatic.

Results

It is convenient to discuss results in terms of (1) insect populations including the pest and associated beneficial or destructive species; (2) the forest stand; and (3) fish and wildlife. A sound evaluation of all these effects is essential for an intelligent and balanced appraisal of the economic and biological values of forest spraying.

EFFECTS ON THE PEST AND ASSOCIATED INSECT POPULATIONS: Reports on the results of DDT applications against forest defoliators consistently show tremendous immediate reductions of most of the insects that are exposed at the time of spraying. Assessments of over 99 per cent control of the spruce budworm were obtained in 1952 in New Brunswick at the 1-lb. dose, and since 1953 at the ½-lb. dose reductions have averaged between 80 and 100 per cent as compared with unsprayed checks. Results that compare favorably to these have been reported from the United States against this insect and from British Columbia against hemlock looper, and more recently, against black-headed budworm.

Results against the pest may also be judged by comparing sprayed and unsprayed populations in the next generation. In New Brunswick and Quebec rapid reinfestation of sprayed areas is a particularly troublesome aspect of the problem. It results not only from a resurgence of residual populations but also from large-scale reinvasions of

moths from surrounding unsprayed areas. It is for this reason that most of the areas involved so far have been sprayed twice and some areas three and four times (Table 2, Figure 4).

Parasites and predators of the pest that are vulnerable at the time of spraying are often much reduced. Some of the more important parasites of the spruce budworm do not seem to be affected as severely as the host, however, and proportionately heavier parasitism in sprayed areas has been reported from both the United States and Canada

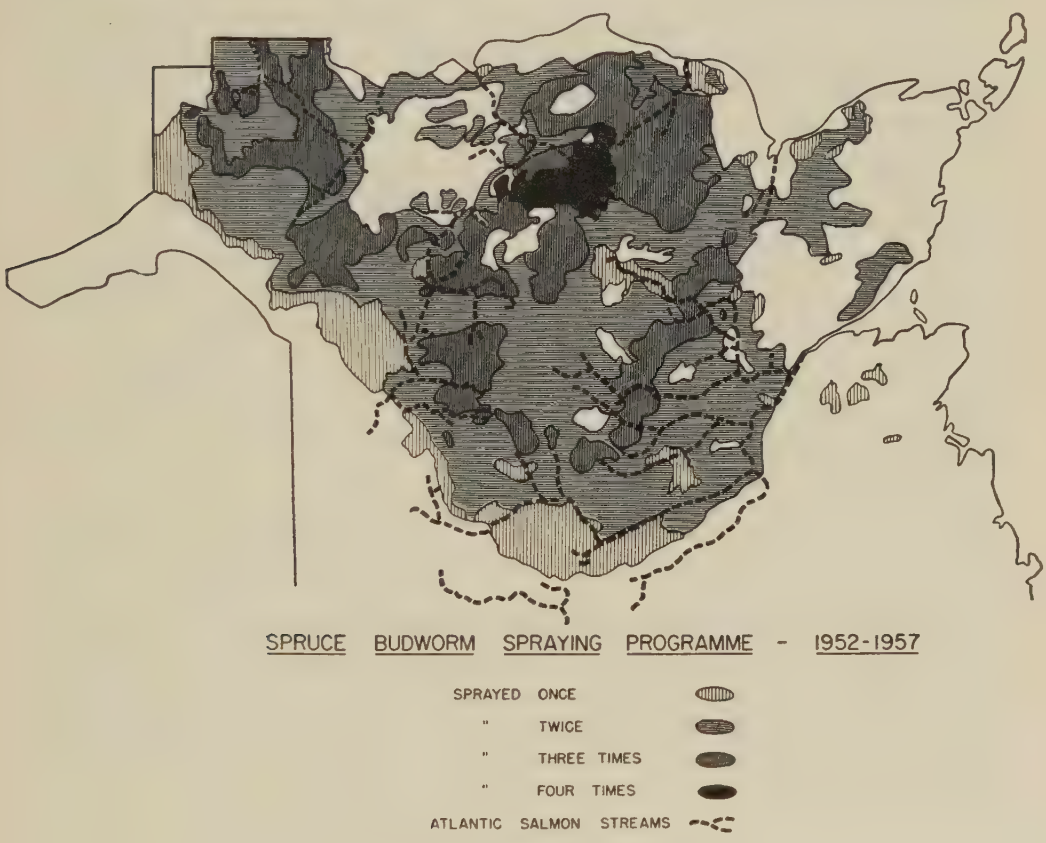

FIGURE 4

(11). New Brunswick studies also show insect predators to be capable of proportionately better survival. Much more remains to be learned about the effects of the treatment on the density-dependant relationships of surviving populations.

Both terrestrial and aquatic insects, other than the pest and its parasites and predators, are temporarily much reduced and some species are affected more severely than others. Excellent control of black flies and mosquitoes usually results. Most terrestrial groups, however, appear to be capable of quick recovery and total numbers of flying insects are often at least as great as in unsprayed areas later in the same season. An interesting study in the United States showed that a sprayed hardwood stand

supported a larger general insect population than an unsprayed stand subjected to exposure by defoliation (8). More work is needed to distinguish between species that are severely affected and those that are not, and to assess the changes that undoubtedly occur in the complex of post-spray populations.

There are no signs yet in Canadian operations that other destructive species are being encouraged. A recent report of widespread mite damage in forests sprayed against spruce budworm in Montana and Idaho, however, emphasizes the fact that this remains a possible hazard.

The phenomenon of resistance to DDT reported for a number of agricultural pests has not yet been encountered in forest defoliators. While this also remains a possibility, its development will probably require the treatment of many more successive generations of the pest than has occurred so far.

EFFECTS ON THE FOREST: From the point of view of the forester, the best evaluation of the results of spraying is in terms of its effect on the forest stand. How successfully was the objective achieved of preventing mortality? What has been the effect on the growth capacity of the trees, and what will be the ultimate silvicultural and economical benefits? As in the case of effects on the pest, a full appraisal calls for assessment of both immediate and long-term effects. Most of the reports available to date from Canada and the United States tell of success in preventing mortality but show little or no concern with the preservation of annual growth. Some change will undoubtedly occur in this emphasis with the fuller utilization and more intensive management of the forest crop.

With each succeeding year of operations it is becoming increasingly difficult to generalize about the condition of sprayed forests in New Brunswick. Conditions ranging from excellent growth recovery to outright mortality are present and often are found within a short distance of one another. There can be little doubt, however, that balsam fir mortality has been substantially forestalled or delayed and that recovery potential remains good over most of the five million acres that are now involved. This is evident from unsprayed check areas where after eight years of severe attack the merchantable component of stands is dead or dying and stocking in younger stands is being depleted. Mortality in sprayed areas is still largely confined to small, scattered patches and chances are good that many of these will be salvaged.

As the outbreak continues in New Brunswick, the problem of assessing the need for respraying is more and more becoming one of estimating the ability of trees to withstand successive attacks and due allowance must be made for their lowered vitality. It now seems evident that spraying may be necessary every other year or, at the most, every third year as long as the outbreak persists and if trees are to be kept alive.

EFFECTS ON FISH AND WILDLIFE: Studies of effects against fish are not a function of the Division of Forest Biology and I shall not presume to review this field here. I might say, however, we follow with keen interest the work of Fisheries Research Board in connection with Atlantic salmon studies and we have welcomed the opportunity to supplement the work of Dr. Ide on the Miramichi (9) in a small way by surveying aquatic insect populations in some sprayed and unsprayed streams in another part of the sprayed area.

There has been relatively little intensive work done in New Brunswick or elsewhere in Canada on effects against wildlife. The concensus, both here and in the United States, however, suggests that dosages customarily recommended against forest defoliators are not likely to have serious adverse effects directly or indirectly against warm-blooded animals. This opinion is supported in an excellent review of the problem by Rudd and Genelly published recently as a Bulletin of the Game Management Branch of Department of Fish and Game, California (15). Some of their recommendations dealing with the use of pesticides in agriculture as well as in forestry may be of interest:

(1) The most selective (pesticide) should be used.

(2) Application should be in strict accordance with prescribed recommendations, should be used only where needed, and should be restricted to the minimum effective amount.

(3) Greater concern should be accorded to widespread application than to local use. Serious effects are more likely to result from treatments over large areas.

(4) Field biologists should participate in the formulation of use procedures and should be consulted at any time when pesticides are applied over a wide area.

(5) Cultural or biological means of control should be substituted for chemical wherever possible.

(6) For the greatest safety, "insurance" or routine applications of pesticides should be avoided.

Concluding Remarks

Nowhere else in the world has the development of large-scale aerial chemical control against forest insects been a more logical development than in Canada. In the few years since the method became economically and operationally feasible, it has taken its place as an adjunct to the management of large, relatively inaccessible forests where other methods are yet ineffective. Further improvements in technique undoubtedly are possible and research on insecticides may be expected to uncover new compounds and formulations that will be more effective, or more selective in their action than DDT. It seems safe to say that the method will continue to be used with improved efficiency against an increasing number of pests.

No large-scale forest spraying project should be undertaken without a full realization of its possible adverse consequences. However, it is not sufficient to oppose the method on the basis of some vague notion of "disturbing the balance of nature." A more precise knowledge must be gained of the effect of introducing the new and powerful control factor into an already complex biological system. The full potentialities of the method can only be determined from tests on a sufficient scale to achieve their purpose, and operations such as those of recent years in Canada provide the necessary opportunities. The biologist's task is to foster the idea that the problems of pest control are primarily ecological and, by means of properly integrated studies of the whole ecosystem, to ensure the safest and most intelligent use of direct control measures.

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Effects of Spruce Budworm Control on Salmon and Other Fishes in New Brunswick

by

Miles H. A. Keenleyside

Fisheries Research Board of Canada, Biological Station, St. Andrews, N.B.

Each spring since 1952 large forest areas of northern New Brunswick have been sprayed with DDT in efforts to control a spruce budworm epidemic. The DDT has been mixed with a special solvent oil and sprayed from airplanes at a concentration of one half pound per acre (one pound per acre in 1952). Some areas have been resprayed at intervals of one, two or three years. In spite of these extensive and costly control measures, the budworm population continued to expand until in 1957 over five million acres of New Brunswick woodland was sprayed, much of it for the second or third time.

In the face of such widespread and repeated applications of DDT many biologists, sportsmen and naturalists have become increasingly worried about the side effects of the insecticide on fish and wildlife in the budworm-infested areas. Fisheries workers have been especially concerned because many species of fish are known to be extremely sensitive to DDT.

Fortunately, a unique opportunity has arisen to study the effects of this DDT spraying on the fish populations of some New Brunswick rivers. Since 1950 the Fisheries Research Board of Canada, through its Biological Station at St. Andrews, has carried out an annual fall census of the young salmon in several branches of the Miramichi River system of central New Brunswick. This programme has involved sampling the fish populations by seining with electrofishing at the same localities each year. Censusing began on the Northwest Miramichi River in 1950, was extended to the Dungarvon River in 1952 and to the Renous and Cains Rivers in 1955. In 1957 the work on the Dungarvon River was discontinued to enable censusing to begin on the Tobique River, the most important salmon angling tributary of the St. John River. A total of 34 census stations is involved: ten on the Northwest Miramichi, six on the Dungarvon, five on the Cains, three on the Renous and ten on the Tobique.

Effects of DDT spraying on young salmon

The relative abundance of young salmon in the Northwest Miramichi branch of the Miramichi River each year from 1950 to 1957 is shown in Figure 1. Data from the first year of censusing (1957) on the Tobique River are included in the figure for comparison. All data are expressed as numbers of fish per 100 square yards of river bottom. The fish are separated into three groups on the basis of size. The smallest fish are fry or underyearlings. Parr less than 10 cm. total length are classed as "small parr"; those over 10 cm. as "large parr". In general, these three size groups correspond to the first three years of life. In the Miramichi River system most young salmon go to sea as smolts at the beginning of their fourth summer.

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Populations of all three size groups of young salmon in the Northwest Miramichi increased gradually from 1950 to 1953 (Figure 1). This increase is probably related to the experimental merganser control which has been carried out on the river since 1950. Control of American mergansers on the Pollett River, N.B., between 1947 and 1950 resulted in a marked increase in the number of smolts leaving the river (Elson, 1950). Following this evidence that reduction of merganser populations benefited young salmon, merganser control was extended to the Northwest Miramichi on an experimental basis in 1950. The experiment was designed to determine whether control of mergansers would eventually increase the numbers of adult salmon from this river taken in the sport and commercial fisheries.

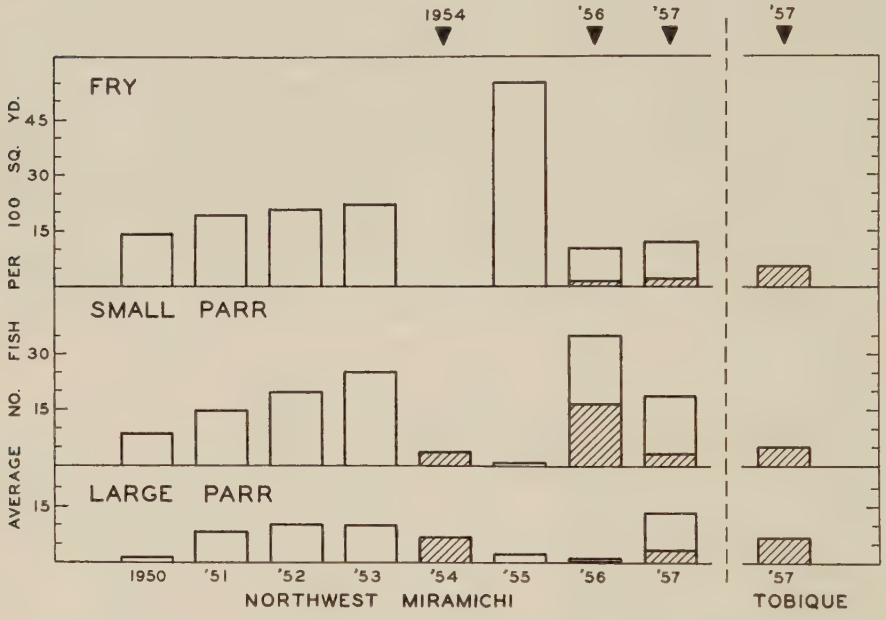

FIGURE 1. *Abundance of young salmon in the Northwest Miramichi and Tobique Rivers. Solid triangles indicate years when DDT was sprayed in the area. Cross-hatching indicates fish found in sprayed parts of rivers.*

In 1954 all stations sampled on the Northwest Miramichi were within the area sprayed with DDT for the first time. The drastic effects of the spray are clearly seen in Figure 1. Not one fry was found that year. Small and large parr were also reduced but to a lesser extent than the fry. Direct evidence of the harmful effects of the DDT was obtained in 1954 by holding salmon parr in cages in several parts of the Northwest Miramichi. From 63 per cent to 91 per cent of those held within the spray area were dead in three weeks, while only 2 per cent died in an unsprayed control stream during the same period (Kerswill and Elson, 1955). The extreme sensitivity of young salmon to DDT was also demonstrated by laboratory bio-assays carried out in the summer of 1957. The *median tolerance limit* (concentration killing one half a sample of fish) for small parr in DDT was 0.049 ppm. for a 24-hour period, and 0.047 ppm. for 48 hours (Keenleyside, —1958).

No spraying was done in the Northwest Miramichi region in 1955 and fry were unusually abundant that year (Figure 1). This heavy fry population may have been due to several factors: (1) less competition for food and space with salmon parr, many of which were killed by the 1954 spraying; (2) great abundance of aquatic Diptera larvae which, in contrast to many of the larger aquatic insect larvae, survive the budworm spraying and which form an important part of the diet of salmon fry in this area; (3) unusually successful spawning of adult salmon in the Miramichi area in 1954.

Small and large parr were scarce in 1955, due to the lethal effect of the 1954 spraying. Those small parr found in 1955 may have been fry which were missed in the 1954 censusing, or they may have been small parr in 1954 which failed to reach large parr size by the fall of 1955 when censusing was done. The aquatic stages of many caddisflies, stoneflies and mayflies are greatly reduced by the DDT spraying (Ide, 1957). Since these insects form the major part of the diet of small and large salmon parr in the Miramichi area, a reduction in their numbers may be reflected in slower growth of the fish.

In 1956 and 1957 only the lower part of the Northwest Miramichi River was within the spray area. In both years approximately the same extent of the headwaters was free of spray. The bars on Figure 1 for 1956 and 1957 are partly cross-hatched and partly open, to represent the proportions of fish found in sprayed and unsprayed parts of the river respectively. Clearly the best fry survival occurred in the unsprayed headwaters. In 1956 small parr were abundant, even in the sprayed section of the river. These were survivors of the very large 1955 fry class. Many of them were in poor condition in the fall of 1956, due to the scarcity of large aquatic insects on which they usually feed. Small parr were surprisingly abundant in the river in 1957. Most of them were found in the unsprayed headwaters, where they were more numerous than the fry of 1956. Some of these fish were probably small parr the year before which had not reached large parr size by 1957. Large parr were scarce in the Northwest Miramichi in 1956 as a result of both the 1954 and 1956 sprayings. In 1957 they were numerous due to growth of the big 1955 fry class, some of which should have reached large parr size by 1957.

All 10 census stations on the Tobique River were within the area sprayed in 1957. Some of them were also sprayed in 1953, 1955 or 1956. Figure 1 shows that young Tobique salmon were found in moderate numbers only in 1957. The figure for fry is misleading, since all fry found in the river were taken at one station, where hatchery underyearlings were planted shortly before censusing. No fry were taken at the other nine stations.

All the data obtained from population assessments on four branches of the Miramichi River since 1950 are summarized in Table I. The table includes the Northwest Miramichi data of Figure 1, but not the Tobique data. Fluctuations in abundance of young salmon over this larger area have been similar to those on the Northwest Miramichi branch. In years when DDT was sprayed populations of young salmon in streams within sprayed areas have been reduced. This reduction has been greatest among the fry. One year later, with no further spraying in the same areas, fry have been very abundant, while small and large parr have been scarce. In areas where no respraying was done for two or three years fry populations were similar to pre-spray levels. Parr, however, were more numerous than before, reflecting growth

Table I

Salmon abundance in the Miramichi River since 1950

	Number of stations studied	Average no. fish per 100 sq. yds.		
		Fry	Small parr	Large parr
Before Spraying	58	23.5	16.7	8.1
Same Stations After Spraying Year of spraying	34	2.5	9.4	3.7
No Further Spraying — 1 year later	17	50.8	0.6	2.8
No Further Spraying — 2 years later	6	24.2	43.9	2.6
No Further Spraying — 3 years later	3	27.8	48.4	29.7

and survival of fry of the first post-spray year. Also, slower growth of small and large parr, due to reduction of their food by spraying, probably results in some parr being included in the same size group for two consecutive years.

It should be emphasized that abundant post-spray populations of small and large parr have been found at only three census stations, where spraying has not been repeated for an interval of three years (bottom line of Table I). These three stations are in the headwaters of the Northwest Miramichi River, which is excellent parr-rearing water. Most of the Miramichi watershed within the range of the present spruce budworm outbreak has been sprayed on successive or alternate years since 1954. Since most young salmon in this area spend three years in fresh water before going to sea, respraying with DDT at intervals of less than three years can affect the same year-classes more than once and thus greatly reduce the potential salmon production of the affected rivers.

Effects of DDT spraying on other fishes

During the annual censusing of young salmon several other species of fish are regularly caught. Changes in abundance of these species have also occurred following DDT spraying. The relative abundance of brook trout (*Salvelinus fontinalis*), eels (*Anguilla rostrata*) and four species of "minnows" in the Northwest Miramichi River since 1953 is shown in Figure 2. Under "minnows" are included four species of Cyprinidae, the black-nosed dace (*Rhinichthys atratulus*), the common shiner (*Notropis cornutus*), the fallfish (*Semotilus corporalis*) and the chub (*Couesius plumbeus*).

Trout are found mainly in the headwaters of the Northwest Miramichi, a section of the river that was sprayed in 1954 only. They were scarce in 1954, recovered gradually until by 1956 they were more numerous than before spraying, and by 1957 were present in about average numbers again (Figure 2). Since the fishing gear used in censusing does not capture trout underyearlings efficiently, only data for yearling and older trout are included in the figure. Fluctuations among these age-groups are similar to those among salmon parr in this headwater section of the river. They are most abundant two years after spraying, when spraying is not repeated.

Eels are present in moderate numbers throughout the Northwest Miramichi. They appear to have been severely affected by the DDT spraying (Figure 2). Their numbers were reduced in 1954 and in 1956, and by 1957 none at all were found.

Minnows are found only in the lower part of the Northwest Miramichi, where spraying occurred in 1954, 1956 and 1957. They have remained abundant throughout this period and were particularly numerous in 1956 (Figure 2). The relative proportions of the four species in this river have been approximately the same during this period. Dace are about 10 times as abundant as each of the other species.

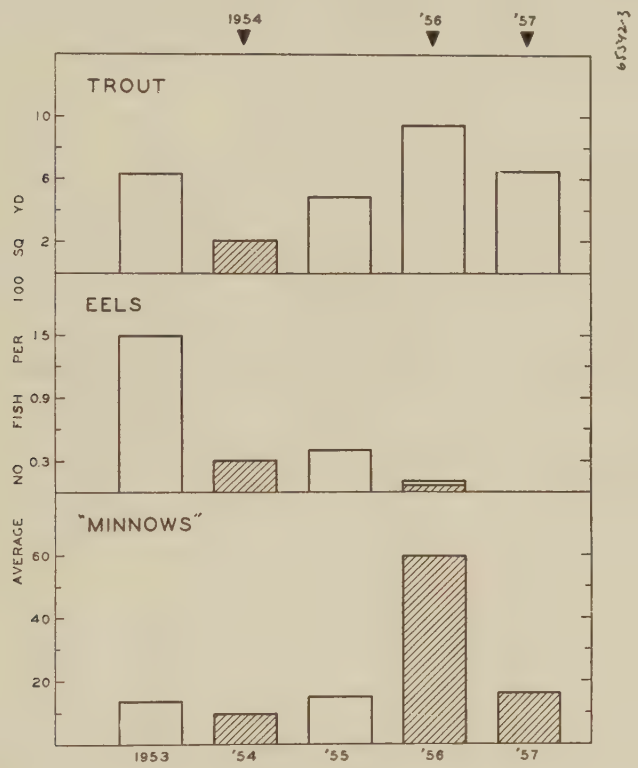

FIGURE 2. *Abundance of several species of fish in the Northwest Miramichi River. Symbols as on figure 1.*

Summary

Several species of fish in New Brunswick rivers have been adversely affected by the widespread aerial application of DDT to the forests of the province as a control agent for spruce budworm. Young salmon, brook trout and eels are reduced in number following spraying. Four species of cyprinids are relatively unaffected by the spray. Salmon populations appear to recover if spraying is not repeated over the same areas for an interval of at least three years. However, much of the budworm-infested woodland has been resprayed at intervals of less than three years. Under these conditions one age-class of salmon can be affected more than once and smolt production from rivers in the area will be seriously curtailed.

Acknowledgements

The raw field data collected annually by the census crews has been processed and tabulated by Dr. P. F. Elson. His assistance in the preparation of this paper is gratefully acknowledged.

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Effects of Black-Headed Budworm Control on Salmon and Trout in British Columbia

by

R. A. Crouter,
Department of Fisheries of Canada
and
E. H. Vernon,
British Columbia Game Commission

Introduction

An infestation of black-headed budworm, *Acleris variana* (Fern.), on Northern Vancouver Island had been under study by the Forest Biology Division of the Department of Agriculture Science Service since 1954. Surveys conducted in the fall of 1955 indicated that the infestation had reached high hazard proportions in the Port McNeill-Port Hardy-Quatsino Sound area. Defoliation within this area in 1956 was severe for the second consecutive year although a survey conducted in the fall of 1956 indicated that the egg count had declined 63 per cent from 1955. Scientists of the Forest Biology Division stated however, that unless over-wintering conditions in 1956 caused a collapse of the infestation, another defoliation would occur in 1957. They stated also that another defoliation, even of medium proportions, might cause tree mortality and top-killing within the high hazard area. For these reasons, it was recommended that consideration be given to carrying out control operations in the spring of 1957.

In June of 1956, an aerial control experiment was conducted within the affected area to determine the dosage and timing of effective DDT treatment.

To consider all aspects of this infestation, the British Columbia Loggers Association formed a Pest Control Committee in 1956. This committee met periodically with the Forest Biology Division and were kept well informed on the status of the budworm infestation. On the basis of the Forest Biology Division recommendation that consideration be given to carrying out control operations in 1957, the committee investigated the factors and requirements associated with the initiation of such a programme. Assurance of financial assistance was received from both the federal and provincial governments. The committee then instituted a plan to conduct an aerial spray programme in the high hazard area during the early summer of 1957. The final decision to spray was to be dependent upon the findings of a survey conducted by the Forest Biology Division in the spring of 1957, which would show if the infestation had significantly lessened over the winter. This survey indicated that severe defioliation would again occur in 1957 and plans for the aerial control programme were finalized.

The possibility that an aerial spray program might be conducted was first brought to the attention of the Department of Fisheries as a result of a report on the preliminary spraying experiment in June of 1956. Following discussion of the matter with the Forest Biology Division, technical personnel of the Department and the B.C. Game Commission were invited to attend meetings of the Pest Control Committee to discuss fisheries problems that might be associated with the proposed spray programme. Both groups remained in close contact with the committee throughout all stages of the operation.

The effects of DDT spraying on fish and fish-food in other regions were closely studied and these were reviewed with the Pest Control Committee. Information on the location of salmon and trout streams within the proposed spray area was presented along with estimates on the size of salmon populations that might be affected. Because of the extreme hazard of aerial DDT spraying to fish populations, it was pointed out to the committee that unless certain major fish producing areas were eliminated from the spray area, there was every probability that extensive fish mortalities would occur. The committee, although sympathetic to the problem, advised that if these areas were eliminated, the control programme would be rendered relatively ineffective and as a consequence they could not agree with the suggested modification. Results from the experimental spraying indicated that a dosage of one-half pound per acre might be effective and the fisheries groups proposed that the recommended dosage of one pound per acre be reduced. The Forest Biology Division indicated however, that there was insufficient evidence that the lower dosage was effective and accordingly could not take the responsibility of recommending a reduction in the dosage. In order to reduce to a minimum the probability of damaging fish populations, the committee did agree however to the following proposals:

(1) Streams would not be used as boundaries for spray plots. This would prevent streams from receiving a double dosage of spray as a result of overlapping.

(2) Pilots would spray parallel to the course of the major streams, keeping one swath width away.

(3) Spray would be shut off where it was necessary to cross streams.

When the final decision to spray was made, a co-operative program was initiated by the Department of Fisheries and the B.C. Game Commission to assess any damage that aerial spraying might cause to the fish or fish-food populations. The Committee agreed that such an investigation would be particularly desirable not only in connection with the proposed programme but also for future reference.

METHOD

Description of Spray Programme

During the period June 10 to June 20 inclusive, 155,000 acres of forest were treated as outlined in Figure 1. Spraying was to commence when the budworm population had developed to the point where the majority of larvae were in the second instar, and with the first and second instars about equally represented. Insect development varied with altitude however and consequently the lower elevations were sprayed first and higher elevations later.

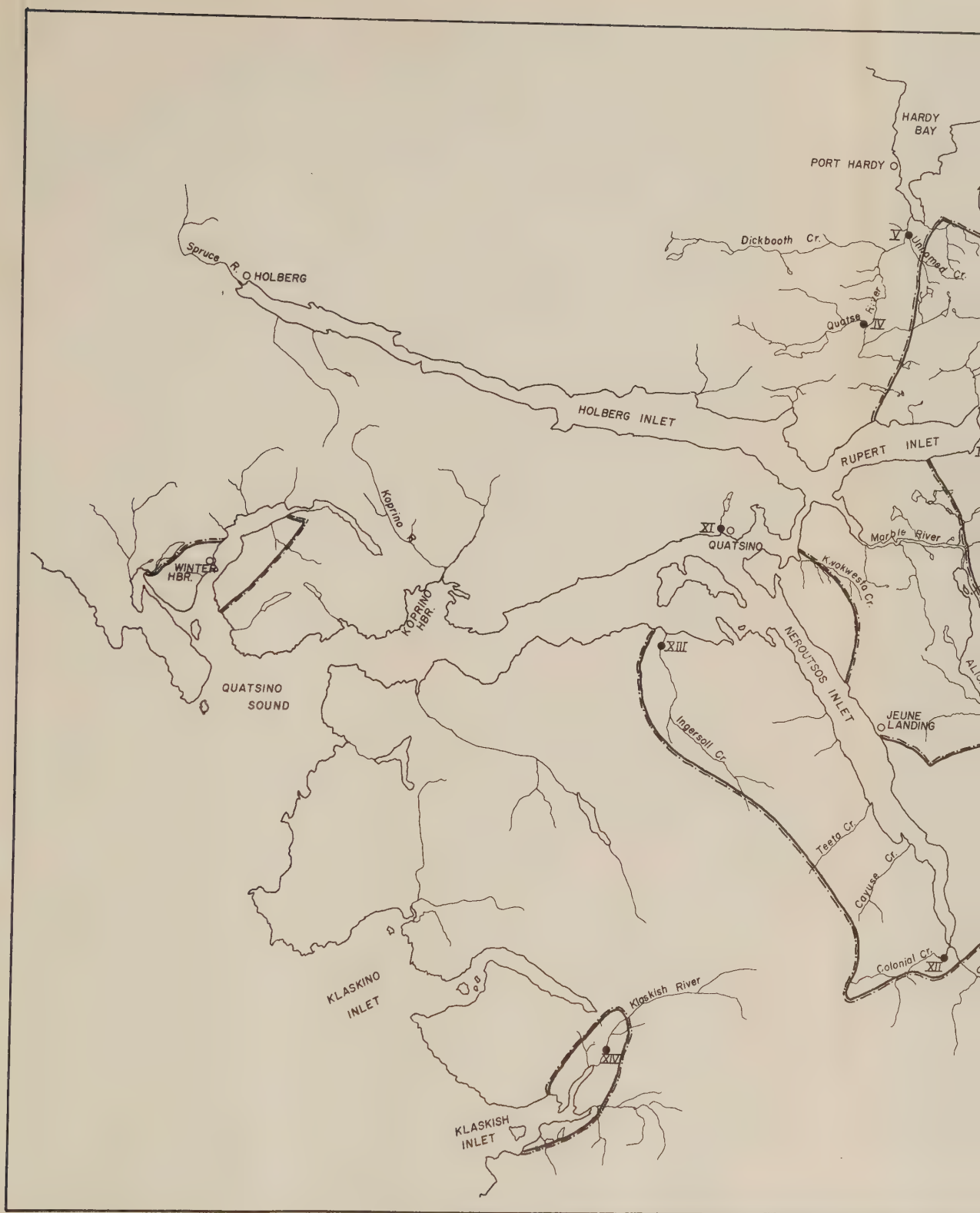

Figure 1—Effects of Black-Headed Budworm Control or

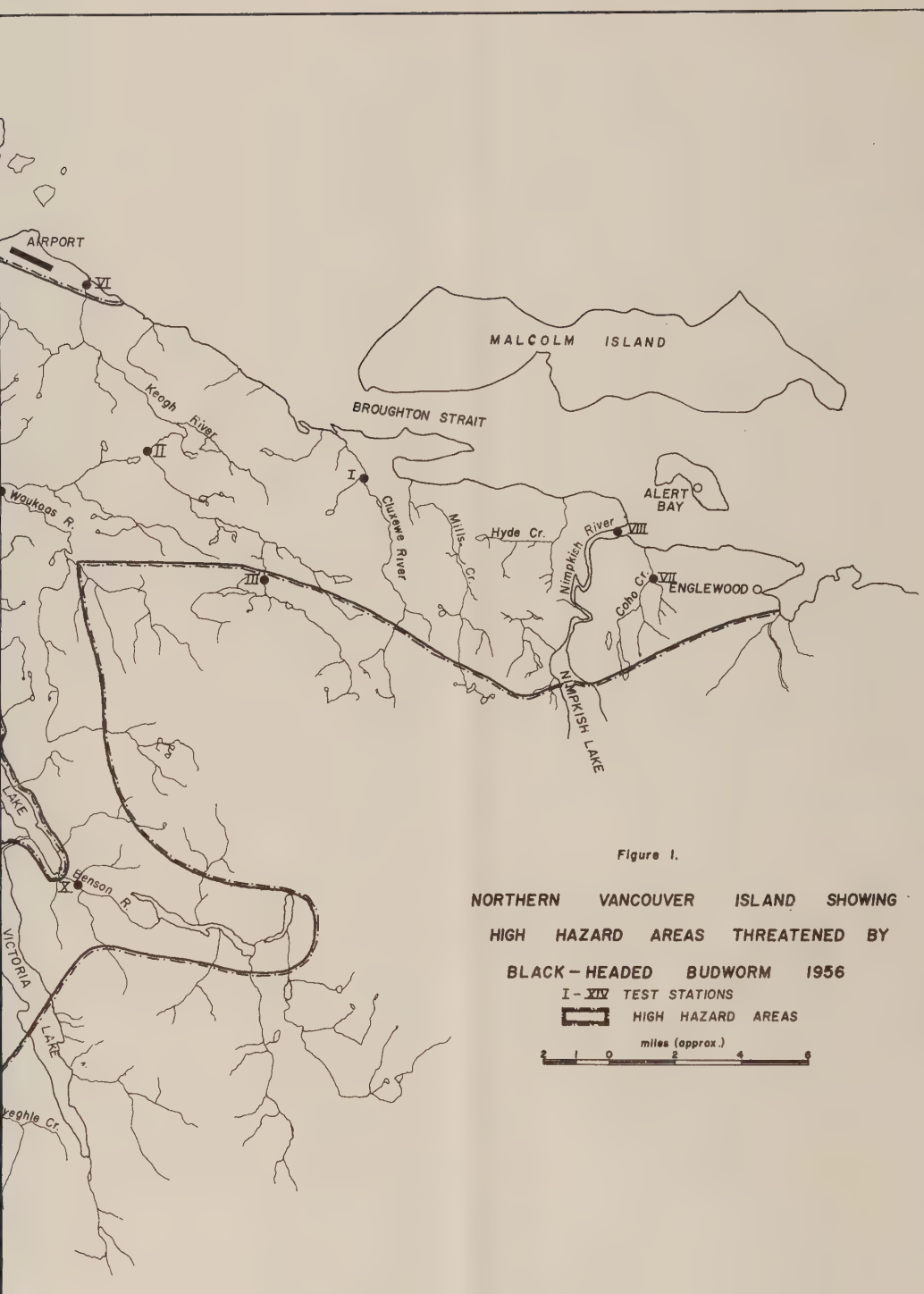

Figure I.

NORTHERN VANCOUVER ISLAND SHOWING HIGH HAZARD AREAS THREATENED BY BLACK-HEADED BUDWORM 1956

I - XIV TEST STATIONS

HIGH HAZARD AREAS

miles (approx.)

2 1 0 2 4 6

Four TBM Grumman Avenger aircraft, operating under contract with Skyway Air Services, conducted the spraying. These aircraft had a carrying capacity of 780 gallons of insecticide and operated at a speed of 150 miles per hour. The formulation constituted one pound of DDT dissolved in a wood penetrating oil with an emulsifier added and blended to one U.S. gallon with diesel oil. The rate of spraying was one U.S. gallon per acre.

In addition to the three preventative measures agreed upon to reduce the probability of severe fish mortality, the Pest Control Committee instituted the following:

(1) The concentration of DDT in the spray formulation was reduced to one-half pound per acre in the area between Englewood and the Nimpkish river, which contains a high proportion of second growth timber.

(2) Spraying on the lower watershed of the Keogh river, which consists partially of cedar swamp, was confined to stands of hemlock.

(3) The south-east side of Colonial Creek, which lies very near the border of the spray area, was not treated.

In order to supervise the control programme, the spray company operated an observation aircraft. The Committee agreed to fly a fisheries observer in this aircraft and an arrangement was drawn up whereby either a Fisheries Officer or an Officer of the B.C. Game Commission was available for every flight. These observations were conducted to determine if it were possible to carry out the suggested preventative measures and also because it was felt that having the officers observe would provide an added incentive for the pilots to effect those measures.

The Assessment Programme

Within the spray area, all five species of Pacific salmon, plus rainbow, cutthroat, and steelhead trout are indigenous. By spray date however, the seaward migration of pink, chum, and spring salmon fry and also that of coho, sockeye and steelhead smolts should have been completed as well as the movement of sockeye fry from stream to lake. The timing of the programme was such that adult salmon would not be present in the streams. Coho fry, trout, and juvenile stages of steelhead were the populations mainly affected by spraying.

The treatment area was situated in an isolated region and access to many of the streams was difficult. There was, however, a system of private and public roads between Port McNeill, Port Hardy and Coal Harbour and in that area, six stations were set up for intensive studies. These were: station I on the Cluxewe river, stations II, III, and VI on the Keogh river, station V on Unnamed creek, a tributary of the Quatse river and station IV, a control on the Quatse river. (See Figure 1).

At each of these stations three live pens were established and in these, coho fry, hatchery fingerling trout, and native steelhead smolts were retained. Mortality, water temperatures, and water levels were recorded daily and water samples were taken at stations II, III, and VI. Bottom samples were taken, using a Surber stream bottom sampler. Samples were taken prior to and during the spray programme and again in late July and in October. In addition, seining was conducted at station VI on the Keogh river. Spray cards supplied by the Forest Biology Division were set out at each station.

Nine stations, consisting of single live pens containing coho fry were established throughout the more remote regions. The mortality after spraying was recorded for comparison with that measured in the intensive study area. In October, bottom samples were taken at each of these stations and at five additional "outside" streams.

The water samples taken at the three stations were sent to the Nanaimo Biological station of the Fisheries Research Board of Canada, and were analyzed for DDT content. In addition, a series of bio-assay tests were made at the Biological Station, to determine the toxicity of both the spray formulation and its component parts to coho fry.

Results

The total loss of fish in the pens was recorded and corrected for natural mortality to give an estimate of the initial kill directly attributable to DDT. Three control

FIGURE 2. *The average natural mortality for fry and fingerlings as at stations I, II, III, V, and VI. The last measure of fingerling mortality represents only the loss at Station I.*

pens were set up outside the spray area; one on the Quatse river, another on the upper portion of the Keogh river and a third on Colony creek. Water temperatures rose to lethal levels at station IV on the Quatse river causing a high mortality, and pen number III on the upper Keogh river was inadvertently sprayed. The mortality in the remaining control pen, station X, was low but it was felt that one pen could not provide sufficient control data.

The natural mortality was calculated by grouping the fish stocked in pens I, II, III, V and VI, which were inspected daily, into one sample and calculating a total cumulative percentage mortality up until spray date. The initial total and the mortality for the individual streams were removed from the group totals as each was sprayed. The calculated percentage cumulative natural mortality for coho fry and hatchery fingerlings is shown graphically in figure 2. The initial DDT mortality figures for stations that were inspected daily have been corrected by taking the total loss after spraying and subtracting the expected natural mortality for that period as inferred from the graph. The figure for those streams that were checked only before and after, were corrected first by subtracting the inferred mortality for the period between the last observation after stocking and the spray date to give an estimate of the number of penned fish affected by spraying. The difference between that figure and the final number remaining alive was corrected again for expected natural loss for the period after spraying.

The corrected DDT mortalities, listed in table I, as measured by the pens range from 0 to over 90 percent. The variation reflects a number of factors such as visibility of streams from the air, drift of spray, forest cover, proportion of the stream sprayed, concentration of DDT used and meteorological conditions.

(1) *The Cluxewe River*—Station I

There was no measurable mortality of either coho fry or hatchery fingerlings attributable to spraying at station I. The portion of this watershed lying within the spray area was extensively logged and spraying was conducted on scattered patches of timber only. The spray formulation in this area did not contain an emulsifier but the scattered spraying probably accounts for the lack of mortality.

(2) *The Keogh River*—Stations II, III, VI

The Keogh river with an estimated escapement of 40,000 coho in 1956, was of vital concern. Three live pens were established on this river, one near the mouth (station VI), another eight miles upstream (station II), and a third (station III), six miles above that. Table I lists the initial mortalities of coho fry as 3.0 per cent at the lower station, 87.2 at the middle and 91.2 at the upper. The hatchery fingerlings suffered losses of 9.5, 84.7 and 51.7 per cent at these respective stations. Subsequent surveys in July and October however, indicated that salmonids were almost absent from the system. The Keogh watershed was sprayed on June 10 and 12. Seine hauls at the lower station on June 17 and June 21 netted an average of 91 and 75 coho fry respectively, four hauls in late July averaged 8 fry and four hauls at the same location in October netted no fish. At the middle station, a series of 25 hauls prior to spraying

Table I

The estimated 1956 escapement to streams within the spray area and the mortalities of coho fry and hatchery fingerlings in pens at the assessment stations.

Stream	Station	1956 Coho Escapement	Corrected Mortality	
			Coho Fry %	Hatchery Fingerlings %
Cluxewe R.	I	2-5000	0	0
Keogh R.		40,000		
	II		87.2	84.7
	III		91.3	51.7
	VI		3.0	9.5
Quatse R.	IV	Control	—	—
Unnamed Cr.	V	500-1000	0	0
Coho Cr.	VII	2-5000	29.7	—
Nimpkish R.	VIII	—	95.9	—
Waukaas R.	IX	500-1000	93.2	—
Colony Cr.	X	Control	—	—
Benson R.	XI	1-2000	72.0	—
Colonial R.	XII	500	94.9	—
Ingersoll R.	XIII	500	0	—
Klaskish R.	XIV	500-1000	83.8	—
Mills Cr.	—	500-1000		
Hyde Cr.	—	50-100		
Lagoon Cr.	—	50-100		
Rupert R.	—	3-500		
Kwokwesta	—	50		
Cayeghle	—	50		
East Cr.	—	50-100		
Teeta Cr.	—	—		
Cayuse Cr.	—	50		

averaged 34 coho fry, six hauls immediately after averaged 3.8 and three hauls in October netted nothing. Seining was not conducted at the upper station but only three fry were observed in 100 yards of stream on October 9.

Coho fry appeared quite numerous at this time in each of the outside streams sampled for bottom organisms. Seining was conducted on two of these streams and on one, the Quatse river, six seine hauls averaged 10 coho fry and one trout fry per set. On the other, the Koprino river, four hauls averaged 17 coho fry.

The initial loss in the Keogh, although quite heavy at the upper and middle stations was negligible at the lower site. The lower four miles of the watershed were only partially sprayed but a heavy oil slick was noted at the pen site. It was felt at the time that the DDT must either have settled out or have been absorbed in some way and that the fry in this area had been unaffected. Analysis of water samples later showed however that toxic concentrations of DDT were present at this site for more than 48 hours after spraying and subsequent surveys indicated a near complete absence of coho fry throughout the system by October. There is a possibility that the coho fry were displaced downstream and eventually to the sea in search of food. Since there is no evidence that fry which enter salt water return as adults, it must be assumed that the mortality of coho fry and trout in the Keogh river approached 100 per cent.

The Keogh river courses through very flat terrain, its valley within the spray area is not well differentiated, and although the forest cover is not dense it largely obscures the actual channel from aerial observation. The lower four miles of the watershed, lying in a cedar-hemlock swamp, were only partially sprayed, as a fisheries benefit, and this may account for the low initial mortality at station VI. It was apparently impossible however to avoid directly spraying the remainder of the system.

The results of bottom sampling show a drastic reduction in aquatic insects at all three stations.

(3) *Unnamed Creek*—Station V

Only the headwaters of this stream, several miles above the pen site were sprayed. There was no measurable initial mortality of either fry or fingerlings and the bottom samples did not show a severe reduction after spraying. Since this is a slow moving stream choked with debris in the upper reaches, it is considered possible that the DDT was removed by adsorption before it could reach the live pen.

(4) *Coho Creek*—Station VII

This stream is small, has a dense forest cover and would not have been easily avoided. It was sprayed at a dosage of one-half pound per acre, as was the adjoining Nimpkish area. A 31.8 per cent total mortality occurred the day after spraying but this did not increase in the following five days and there were very few distressed fish observed in the stream. This relatively low mortality is probably attributable to a combination of good forest cover and the lower dosage of insecticide.

(5) *Nimpkish River*—Station VIII

The fry mortality at station VIII is listed in Table I as 95.9 per cent. The portion of the system sprayed however, between Nimpkish lake and the mouth of the lower Nimpkish river, is not utilized by coho and was presumably barren of juvenile salmon during the insect control program. Fry for the test pen were transported from Coho creek.

Although it is assumed that there was no mortality in the Nimpkish river itself, the insecticide which caused a loss in the pen was carried into the estuary, killing large numbers of chum salmon fry and a few juvenile coho and spring salmon which had moved into the estuary from Johnston Straits.

The Nimpkish is a large, wide river, easily seen from the air and is situated in an area that was treated with a one-half pound per acre dosage of DDT. The spray company agreed to fly the Nimpkish parallel to its course and to keep one swath width away from the river-bed. This stream should have been the most easily avoided in the spray area. The toxic concentration of insecticide must be attributed either to human error or to drift of spray.

(6) *Waukaas River*—Station IX

Station IX, sprayed on June 10, incurred a calculated DDT mortality of 93.2 per cent. A heavy oil slick was observed on the 10th, a 35 per cent mortality was recorded by the 11th, on the 12th numerous dead coho fry and trout yearlings were observed in the stream and the pen mortality had risen to 89 per cent. On June

15 a few coho fry were observed alive in the stream but by October there were virtually none in evidence. The October bottom sample was almost barren, the total catch being one mayfly nymph and one annelid in 10 square feet.

The Waukaas river lies in very flat terrain and has a medium forest cover. It would have been fairly difficult to avoid and the assessment results indicate that it received a full dosage of spray.

(7) *Benson River*—Station XI

The Benson river, which flows into Alice lake on the Marble system, drains a narrow steep valley and the river channel is quite visible from the air. Prior to spraying, the pilots felt that this stream could be avoided. The assessment results and observations indicate however that the actual mortality was severe, being recorded at 72 per cent in the pen. On the afternoon of spray day, June 18, a number of dead coho fry, yearling trout and sculpins were seen at the mouth of the river on Alice lake, and it was noted that an extremely heavy oil slick extended one-half mile into the lake. An oil slick was observed also on three lakes in the upper Benson watershed and a trout kill was reported in Victoria lake, which adjoins Alice lake.

There were no fry observed in the Benson river during the October survey and the bottom samples were extremely poor in aquatic insects.

(8) *Colonial River*—Station XII

The corrected mortality at the station XII pen, which was sprayed on June 14, is listed as 94.9 per cent. The stream was checked on June 19, five days after spraying. There were no dead fish of any kind in evidence but a reduction of coho fry was reported, based on observation only. In October, coho fry were fairly numerous and the yield of the bottom sample, although lower than that of control streams, was not poor.

The actual mortality of coho fry in Colonial creek was probably light. Heavy rain occurred on June 10 and June 16, increasing the volume and velocity of the stream flow. The pen was situated in an unprotected site and much of the mortality was probably caused by excessive velocity.

The valley of Colonial creek is not steep but the river channel is quite visible from the air. In addition, the south-east side of the valley was not sprayed. These two factors undoubtedly contributed to the success in avoiding severe mortality in this stream.

(9) *Ingersoll River*—Station XIII

There was no mortality, attributable to the spraying, recorded at station XIII. The river is situated in a well-defined, unlogged watershed and is easily located from the air. Observers report that the aircraft did not appear to spray within one-half mile of the river itself and also that no oil slick was observed at any time. The area was sprayed on June 19, there was a heavy rainfall on the 21st and 22nd and the pen was removed June 23. The number of aquatic insects in the bottom sample, taken in October was comparable to that of the control streams and there appeared to be no depletion of coho fry.

(10) *Klaskish River*—Station XIV

The DDT mortality of coho fry in the Klaskish river pen has been calculated at 83.8 per cent. On June 18, three days after spraying, several hundred coho fry and few cutthroat trout, measuring up to eleven inches long were found dead at the mouth of the river. A drastic reduction in the number of coho fry present in the stream was also reported at that time. In late October, a bottom sample was taken and several seine hauls were made. There were no coho fry either caught or observed but the bottom sample, although lower in aquatic insects than those of the control streams, was much better than the samples taken on the Benson, Waukaas or Keogh rivers which suffered similar fish mortalities. Only the lower two and one-half miles of this stream, which includes most of the spawning and rearing area, were sprayed.

The insect populations were probably being repopulated from the upper areas.

The Klaskish river is situated in a mountainous area and is clearly visible from the air. Observers report that on at least one occasion, an aircraft crossed this stream emitting spray but in general the pilots did attempt to avoid directly spraying the river channel. The observers reported also, however, that the spray drifted very badly.

The fish mortality in the Klaskish river was apparently severe, that of the coho fry exceeding 80 per cent.

Bottom Samples

A series of nine bottom samples were taken at stations I to VI throughout the period from May 27 to June 24 and two further samples were taken on July 25 and 30. Between October 8 and 21 samples were taken at these same stations, with the exception of number V, and in the Waukaas, Colony, Benson, Colonial, Ingersoll and Klaskish systems. Seven streams outside the spray area but in the same general region were also sampled for bottom organisms during this period. These were White creek, a tributary of the Quatse river, the Koprino river and Colony creek flowing into Quatsino Sound, the Spruce river at Holberg and the San Josef and Fisherman river. on the extreme northern tip of Vancouver Island. The individual bottom samples taken from May to July were generally of one square foot in size, the October samples inside the spray area were ten square feet and those taken outside were five square feet.

The organisms of each bottom sample were enumerated, classified, dried and weighed. In general, mayfly larvae were the most numerous of the insect life, followed by stonefly and then caddis-fly larvae and various species of diptera and coleoptera. A species of oligochaete was present in most of the samples and at the locations where aquatic insect life was severely reduced, was sufficiently numerous to mask the loss of other forms on the basis of total number or total weight of organisms per unit area. Since these oligochaetes are not utilized for food by fish they were removed from the sample. Forms such as turbellaria, hirudinea and gastropoda were not common.

With one exception, the loss of bottom organisms in the individual streams parallels closely the loss of fish. Table II lists the weights and number of organisms per square foot of stream bottom for both spray and control streams from May to October. The weight data is shown graphically in Figure 3.

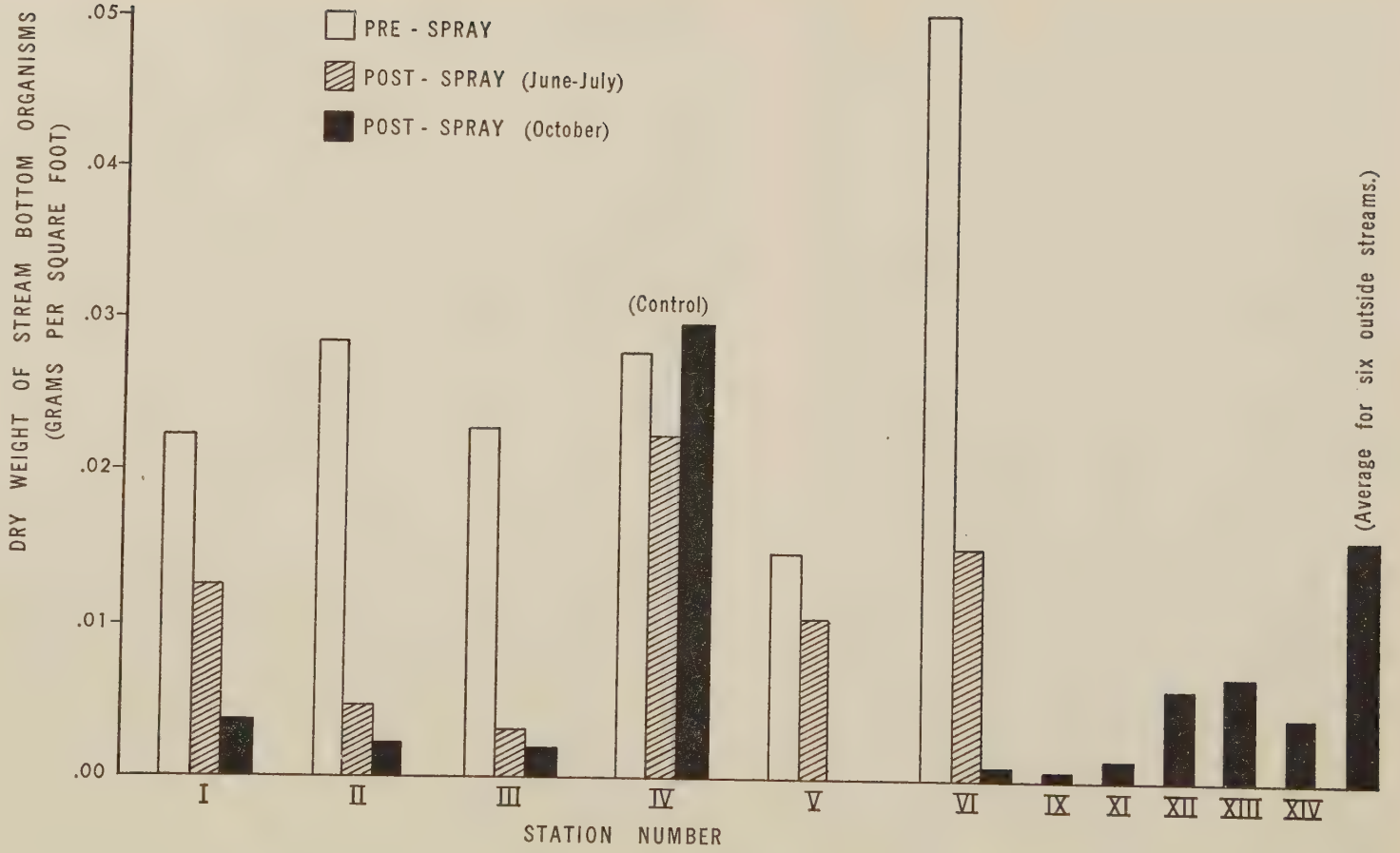

FIGURE 3. *The average weight of bottom organisms at several stations before and after spraying.*

Table II

The weight and number of organisms per square foot of stream bottom prior to spraying, immediately after and in October, Oligochaetes were excluded.

Stream Station		Prior to Spraying	After Spraying (June-July)	After Spraying (October)
STATION I	Number	23.5	5.25	6.7
(Cluxewe River)	Weight (Grams)	0.0223	0.0124	0.0024
STATION II	"	42.0	0.78	2.2
(Keogh River)		0.0285	0.0038	0.0021
STATION III	"	26.9	5.21	5.9
(Keogh River)		0.0226	0.0029	0.0018
STATION IV	"	24.5	12.6	13.0
(Quatse R. Control)		0.0287	0.0212	0.0295
STATION V	"	21.7	20.0	—
(Unnamed Cr.)		0.0144	0.0103	—
STATION VI	"	37.3	9.2	1.2
(Keogh River)		0.0500	0.0147	0.0004
STATION IX	"	—	—	0.1
(Waukaas River)		—	—	0.00002
STATION XI	"	—	—	0.8
(Benson River)		—	—	0.0010
STATION XII	"	—	—	11.4
(Colonial)		—	—	0.0058
STATION XIII	"	—	—	17.2
(Ingersoll River)		—	—	0.0065
STATION XIV	"	—	—	5.9
(Klaskish River)		—	—	0.0040
Average of 6	"	—	—	19.1
Outside Streams		—	—	.0153

Streams in which there was a severe fish mortality such as the Keogh, Waukaas and Benson rivers, demonstrated a drastic reduction in aquatic insect life. The number and weight of organisms in others such as the Ingersoll, Colonial and Cluxewe rivers, which did not suffer a large fish mortality, were within the range of the control stream samples taken in October. The single exception to this parallel was the Klaskish river. Although results from the live pen on this stream indicate a mortality to coho fry of over 80 per cent, and observations suggest that this measurement is minimal, the bottom sample does not show a paucity of insect life. Only the lower two and one-half miles of the Klaskish, which includes most of the available spawning area, were sprayed. By October, when the sampling was carried out, the insect life could have been repopulated from the upper areas.

As already stated, the most numerous forms prior to spraying were mayfly, stonefly and caddis-fly larvae in that order. Table III compares the average number

of each of these forms at stations I, II, III, V and VI; prior to spraying in June, and after spraying in June, July and October. The mayfly larvae, although suffering the greatest reduction in numbers, were still the most numerous after spraying. Caddis-fly larvae by October were non-existent in the samples.

Table III

Comparison of the average number of Plecoptera, (Stone-flies), Ephemeridia (May-flies) and Trichoptera (Caddis-flies) per square foot of stream bottom before spraying, immediately after and in October at stations sprayed in the intensive study area.

——	Station	Plecoptera	Ephemeridia	Tricoptera	Total Area Sampled in Sq. ft.
Prior to Spraying (May-June)	I, II, III V, VI	2.5	20.0	4.0	22
After Spraying (June-July)	II	0.7	2.4	1.1	46
After spraying (October)	I, II, III, VI	1.2	1.7	0	50

Table II compares the number and weight of bottom organisms for the same three periods as above for each station and stream sampled. In general, the proportion of larger forms in the sprayed stream samples was considerably reduced after spraying. At stations I, II and III, the number of organisms per unit area showed an increase over the June-July samples but the average weight declined. Both the number and the weight of organisms were lower in the October sample at Station VI on the Keogh river, but the weight per unit area was disproportionately low.

In summary, the major fish food organisms of the Keogh, Waukaas and Benson rivers have been reduced to drastic proportions and will be of insignificant food value for at least the 1957 season. The abundance of major organisms in the other streams sampled varies, but the overall food production should not be greatly affected.

Bio-Assays

In conjunction with the assessment programme, a series of bio-assay tests were conducted at the Nanaimo Biological Station of the Fisheries Research Board of Canada, to determine the toxicity of the spray formulation and its component parts. The results of this bio-assay programme have been reported by Alderdice and Worthington (see page 41, this issue). On the basis of the bio-assay tests, Alderdice considered the "safe" concentration of spray formulation to be below 0.05 parts per million and that for the emulsifier, Atlox 2082A, to be 2.1 parts per million. Coho salmon under-yearlings were used as subjects for the tolerance studies.

Analysis of Water Samples

Water samples were taken at the three stations (II, III, and VI) on the Keogh river and at station IX on the Waukaas river. It must be emphasized that these were

two of the streams most affected by spraying. The samples, taken between June 10 and 22, arrived at the Biological Station on July 12. They were placed in storage at 0° to 4° C. on arrival and were analyzed for DDT content between October 2 and 7. It would appear that the pH of the water samples had risen on standing and the possibility exists that some degradation of DDT in the samples may have resulted. Results of the analysis are listed in Table IV.

Table IV

Results of analysis for DDT content of water samples taken in the area sprayed for budworm control, Vancouver Island, June 1957.

Station	Date Sampled	Time	Date Analyzed	DDT. ppm.	P = .01 limits. ppm.	pH of sample
						(Oct. 24, 1957)
II.....	10 June	0800	7 Oct.	0.13	0.09 —0.19	9.6
	10 June	1930	3 Oct.	0.22	0.16 —0.32	9.7
(sprayed	11 June	0900	3 Oct.	0.20	0.14 —0.29	9.8
June 10)	12 June	0930	3 Oct.	0.03	0.019—0.044	9.85
	13 June	1100	2 Oct.	0.22	0.16 —0.32	9.9
	14 June	1000	4 Oct	0.18	0.13 —0.26	9.6
	18 June	0900	7 Oct.	<0.01	—	9.7
	20 June	0930	2 Oct.	0.40	0.28 —0.58	9.65
III.....	10 June	1000	7 Oct.	<0.01	—	9.7
	19 June	1000	7 Oct.	<0.01	—	9.85
(sprayed	19 June	1830	2 Oct.	0.37	0.26 —0.52	9.75
June 19)	20 June	0730	2 Oct.	<0.01	—	9.9
	21 June	0730	7 Oct.	0.03	0.019—0.044	9.75
	22 June	0730	3 Oct.	0.10	0.07 —0.15	9.8
	22 June	0800	2 Oct.	0.15	0.11 —0.22	9.5
VI.....	10 June	1330	3 Oct.	0.07	0.048—0.11	9.75
	11 June	1100	4 Oct.	0.28	0.19 —0.39	9.75
(sprayed	12 June	1300	2 Oct.	0.21	0.14 —0.30	9.75
June 10 and 12)	18 June	1200	7 Oct.	0.01	—	9.65
IX.....	10 June	1200	4 Oct.	0.06	0.042—0.090	9.6
	11 June	0930	4 Oct.	0.05	0.033—0.074	9.65
(sprayed	12 June	1600	3 Oct.	0.07	0.048—0.11	9.8
June 10)	14 June	1130	4 Oct.	0.02	0.013—0.031	9.1

The Waukass river was sprayed on June 10. On that date, the DDT content, as measured, was 0.06 p.p.m., and three days later the concentration was found to be 0.07 p.p.m. However on June 14 the concentration of DDT had dropped to 0.02 p.p.m., less than the safe level of 0.05 p.p.m. (Table IV). It can therefore be stated that a toxic concentration of the insecticide was present in the Waukass river for at least three days.

As outlined, previously, on the Keogh river, station VI was situated near the mouth, station II eight miles upstream and station III six miles above that. Most of the watershed below the upper station was sprayed on June 10 although a small part of the lower area was treated on June 12. The upper watershed, which included station III, was sprayed on June 19.

A water sample taken at the middle station 12 to 14 hours after spraying on June 10, on analysis, showed a concentration of 0.22 p.p.m. of DDT while that of a sample taken four days later was measured at 0.18 p.p.m. By June 18, eight days after spraying the concentration of DDT had dropped below the measurable limit of 0.01 p.p.m. but in a sample taken two days after the June 19 spraying of the upper area, the concentration had risen to 0.40 p.p.m. The middle portion of the Keogh river was subjected therefore to at least five days of toxic DDT levels.

A water sample taken at Station III, sprayed on June 19, had a DDT content of 0.37 p.p.m. on spray day. Four days later the concentration had only dropped to 0.15 p.p.m., very much above the safe level.

Water samples were taken at the lower station (VI) on June 10, 11, 12 and 18. In the first two days after spraying, the concentration was very high but by June 18, had dropped below the 0.01 p.p.m. limit. Since sampling was discontinued at this station on June 18, the effect of the upper watershed spraying of June 19 was not measured.

This was the station at which there was no measurable initial fish mortality but at which there were no juvenile salmonids present in October.

Discussion

As stated earlier, the hazards of aerial spraying with DDT to fish and fish-food populations were fully realized by the fisheries groups prior to spraying. Although it was also realized that the preventative measures agreed upon would not eliminate entirely the probability of severe fish mortality, they did constitute an improvement over current practices. The success of avoiding mortality was therefore dependent upon the ability of the pilots to effect those measures.

The actual spraying was kept under close observation by fisheries personnel. The air crews were well experienced in this type of spraying and all those concerned with the aerial control program, including the pilots, expressed repeatedly the desire to avoid damage to the fish populations within the area. The fisheries observers agreed that in general the pilots made a sincere attempt to carry out the preventative measures agreed upon. Presumably, the equipment and personnel used in the insect control programme were of the highest calibre, all practical preventative measures (short of non-spraying) were followed and a sincere effort made to implement those measures yet the mortality in at least four major streams approached 100 per cent. The meteorological conditions during the spray period, although possibly adverse for spraying, were not unusual for the region at that time of year.

There was a large variation in the effect of the DDT application on the fish population. The mortality of coho fry ranged all the way from zero on the Ingersoll to almost complete annihilation on the Keogh and Waukaas rivers. The reduction in aquatic insects paralleled quite closely the loss of fish. Although the effects of spraying varied with each stream, the following points might be noted:

(*a*) Fish mortality was high in large streams flowing through flat terrain with a fairly dense forest cover (e.g. Keogh and Waukaas rivers). The probable reason is that they are not clearly visible from the air.

(*b*) Fish mortality was high in large streams flowing through steep-walled valleys (e.g. Klaskish and Benson rivers). Watersheds of this type are sprayed on contours and in the particularly rugged terrain with its attendant unpredictable air currents, the control over spray deposition must be very slight.

(*c*) Fish mortality was low in streams situated in well differentiated but not particularly steep-walled valleys (e.g. Ingersoll and Colonial rivers). These streams are visible from the air and there is apparently better control of spray deposition.

(*d*) Fish mortality was relatively low in a small stream with a dense forest canopy (e.g. Coho creek). This stream was sprayed at a dosage of one-half pound of DDT per acre. In view of the heavy mortality of chum salmon fry in the Nimpkish river, which was also sprayed at the same dosage, it must be concluded that the reduction in concentration was not the significant factor in the low mortality in Coho creek.

(*e*) There was no measurable initial fish mortality in a small stream which was sprayed in the upper area only, several miles above the live pen (e.g. Unnamed creek). It is considered probable that the concentration of DDT was reduced below toxic levels by adsorption.

Loss of Salmon

Except for the loss of many thousands of chum fry which were killed in the estuary of the Nimpkish river, the damage to salmon stocks was confined to the mortality of coho fry. There are 18 salmon streams within the spray area, excluding the lower Nimpkish river which does not serve as a spawning or rearing area for coho, and in ten of these the 1956 coho escapement was estimated at 500 or more. The effects of spraying were measured in nine of those ten major streams as shown in Table I. In four of these, the Keogh, Waukaas, Klaskish and Benson rivers the mortality of coho fry approached 100 per cent and in a fifth, Coho creek, the loss was calculated at 30 per cent. In the four others that were sampled, the Ingersoll, Colonial, Cluxewe, and Unnamed creeks, there was not a large mortality. Mills creek, south of Port McNeill, was the only major stream where mortality was not assessed.

The damage to salmon stocks within the spray area was over-shadowed by the loss of coho fry in the Keogh river, where the progeny of an estimated escapement of 40,000 adult coho were almost completely annihilated. The escapement to the other three major streams affected by spraying totalled between 2,000 and 4,000.

The coho salmon has a predominant three-year life cycle and very little overlapping from other year classes can be expected. Even assuming that there was not a complete loss of fry in the four grossly affected streams, and assuming also that there will be some smolt production, judicious management will not restore the population for many cycles. The economic loss will then be accumulative until the escapement is restored once again to the 1956 level.

In order to alleviate this loss, the most obvious assistance to management would be artificial restoration. The only immediate measure would be the release of under-

yearlings, preferably from neighbouring streams. The problem of successfully transporting significant numbers to the streams in this isolated region, if the underyearlings were available, would be extremely difficult. In addition, it is doubtful if the streams in their present unproductive state could support a significant transplant. The best chance for success of artificial restoration may be the introduction in 1959 of large numbers of eggs. These could be flown to the Port Hardy airport and distributed to the respective streams.

Loss of Trout

Rainbow, cutthroat, and steelhead trout are indigenous to all streams in the region. It was not possible to estimate the number of trout within the spray area and knowledge on the size of the steelhead trout escapement is lacking. Unlike Pacific salmon, the steelhead and both species of trout spawn in the spring and by spray time in mid-June the spawn had probably reached the alevin stage. It is highly probable that the alevins are susceptible to DDT and in fact, a paucity of fry of the year were observed in October within the spray area. Seining was conducted in two control streams, the Koprino and Quatse, and trout fry were present in normal numbers.

In general, steelhead trout spawn in the spring, the fry emerge in the early summer, spend the remainder of that year and the whole of the following year in fresh water before going to sea in the late spring of the third year. In 1957, the seaward migration of smolts was well underway by spray date and only the latter portion would have been affected by DDT. Results from the holding pens indicate that the initial mortality to steelhead smolts was relatively light as compared to that of coho fry. The loss of migratory steelhead smolts, consequently, may not have been severe. The real damage to the steelhead populations would have been the loss of underyearlings and very probably the spawn of the year, in which case two consecutive year classes would have been affected. This loss was particularly noticeable in the Keogh river, where in October, there was a near complete absence of all juvenile salmonids.

In general, the relative mortality of trout in the affected streams could be expected to parallel the loss of coho fry. If this assumption is correct, of the major streams, the greatest losses would have occurred in the Keogh, Benson, Klaskish and Waukaas rivers. Of these four, only the Keogh is utilized at present to any degree by anglers, but the other three do have a potential. The resident trout of the Keogh river may repopulate quickly from several small lakes on the system but regeneration of the steelhead population will be a slow process. The trout population in the Benson river will likely be rehabilitated from the resident trout populations of Alice Lake. In October, angling was good in the lower portion of the stream. The Klaskish river is situated on the west coast of Vancouver Island and because of the isolated region, will not be an important angling stream for many years. Only the lower two and one-half miles of this stream was affected by spraying and repopulation should proceed rapidly from the upper areas. The Waukaas river is not a major angling stream, but it is considered that the resident trout and fresh water stages of steelhead trout were eliminated by spraying.

A few lakes received marginal doses of insecticide and although trout mortality was reported in the two largest, Alice and Victoria, it is considered that generally the losses were relatively small and will be quickly replaced by natural propagation.

In summary, the loss in number of trout by spraying was undoubtedly large. This district is however isolated and under the relatively light angling pressure imposed upon them at present, the stocks of trout should repropagate to pre-spray levels quickly. The steelhead trout on the other hand will take a number of years to overcome the effects of spraying which undoubtedly affected two consecutive year classes.

Reduction of Aquatic Insects

The reduction in aquatic organisms within the spray area as measured by bottom sampling, followed the same pattern reported by Ide (1956). The major loss was confined to aquatic insect larvae, particularly the larger forms of stoneflies, mayflies and caddis flies. Mayfly larvae were the most numerous form both before and after spraying but also suffered the great percentage reduction. Caddis-fly larvae by October were almost absent in the samples taken from the four major streams affected.

Ide (1956) reports that in a tributary of the Miramichi, which was included in the extensive Maritimes spraying of 1954, the emergence in the year of spraying consisted of large numbers of minute chironomids and very few of the larger insects. In the year following spraying the bulk of insects emerging was less than half that of the control stream and that was made up predominantly of small chironomids. There was a lack of caddis flies.

In the second year after spraying, the bulk of the emergence from the spray stream was still considerably lower than that of the control, and minute chironomids continued to dominate the emergence of the former. There were fewer species in the spray stream, stoneflies were still present in only insignificant numbers and large forms of stoneflies and mayflies were absent from the samples.

Kerswill (1957) found on the Miramichi that the normal diet of underyearling Atlantic salmon consists largely of small insects, but that older juveniles feed mainly on larger forms and do not appear to utilize the small forms even when the latter are abundant.

On the basis of these findings, the productivity of streams that are destitute of aquatic life at present will remain low for at least two seasons.

Summary

During mid-June of 1957, an aerial spraying programme was conducted on 155,000 acres of timberland on the northern portion of Vancouver Island, in an attempt to control an outbreak of black-headed budworm. The formulation used was one pound of DDT in a solvent with an emulsifier added and blended and one U.S. gallon with diesel oil. This was applied at the rate of one U.S. gallon per acre.

The damage to the fish and fish-food populations was assessed on the major streams and on four of these, was found severe. The fish mortality was confined generally to coho fry, trout, steelhead yearlings and possibly alevins of both trout and steelhead.

In the four major streams affected by spraying, the progeny of an estimated 1956 escapement of 43,000 coho adults and the juvenile stages of several thousand steelhead and trout was almost eliminated.

The reduction of aquatic insects parallels the loss of coho fry and the productivity of several streams is not expected to return to adequate proportions for at least two years.

A series of bio-assays was conducted at the Nanaimo Biological Station of the Fisheries Research Board of Canada. The tests indicate that a safe concentration of the formulation used in this insect control programme is below 0.05 parts per million. Analysis of water samples taken in the field showed that toxic concentrations of DDT existed at four test stations for more than three days after spraying.

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Toxicity of a DDT Forest Spray to Young Salmon

by

D. F. Alderdice and M. E. Worthington

Fisheries Research Board of Canada, Biological Station, Nanaimo, B. C.

In June, 1957 an aerial DDT spray programme was carried out to control black-headed budworm in an area of northern Vancouver Island, B.C. This report summarizes a series of laboratory tests conducted to determine the tolerance of a representative species of Pacific salmon to the DDT formulation used in the spray programme. The study provides information relating to an extensive field survey conducted to assess the effects of spray deposition on aquatic fauna within the sprayed area (Crouter and Vernon, 1959, see page 23, this issue).

Method

Following consultation with members of the Department of Fisheries and B.C. Game Commission, the following programme was undertaken:

(*a*) Examination of tolerance to Atlox 2082A, the spray formulation emulsifier.

(*b*) Examination of tolerance to the spray formulation used in the aerial spray programme.

(*c*) Comparison of the potency of the aerial spray formulation with a DDT-acetone standard.

Accordingly, the following materials were used in the tolerance tests:

(*a*) Emulsifier—Atlox 2082A, a preparation of "alkyl aryl sulphonate" and "polyoxyethylene sorbitan esters of mixed fatty and resin acids" manufactured by the Atlas Powder Company.

(*b*) Aerial Spray Formulation—made up in the following manner:

25 g. 100% Tech. "Montrose" DDT

7.14 g. Base Oil

3.6 g. Atlox 2082A

One volume of the above mixture is diluted with 1.2 volumes of medium grade diesel oil. The "base oil" used was "Standard Base Oil (Wood Treating)" manufactured by the Standard Oil Company. "Medium grade diesel oil" was obtained from the Imperial Oil Company of Canada. DDT was obtained from the Stauffer Chemical Company, Portland, Oregon.

(*c*) DDT-Acetone Standard—Maintaining the same proportions of DDT and Atlox 2082A as in the aerial spray formulation, acetone was substituted for the base oil and medium grade diesel oil.

Estimation of DDT content of solutions used in the tolerance tests and of the water samples collected in the spray area was carried out by a modification of the method suggested by Amsden and Walbridge (1954). A standard curve was prepared by analyzing for known amounts of DDT in acetone solution. No significant difference was obtained in a comparison of results from these standards with those obtained using aerial spray formulation added to water with subsequent separation of DDT with isopropyl ether. The resulting standard curve relating DDT concentration to spectrophotometric absorbance was used for estimating DDT levels in the succeeding tests. In all cases absorbance corrections were made with reagent blanks run concurrently. The method provided measurement of DDT down to 0.01 p.p.m. after extraction of the DDT from water. Colorimetric determinations were made using a Beckman DU Spectrophotometer at a wave length of 4700 A° and 0.03 mm. slit width.

Coho salmon (*Oncorhynchus kisutch*) underyearlings were considered as an appropriate species for determination of tolerance to DDT. The tests conducted with Atlox 2082A were carried out in August, 1957, and the coho underyearlings used averaged 6.89 cm. in length and 4.08 g. in weight. Test fish were exposed to various concentrations of Atlox 2082A at a ratio of 0.88 g. of fish per litre of solution. The tests conducted with the aerial spray solution and DDT-acetone standard were carried out in October, 1957. The coho underyearlings used averaged 8.81 cm. in length and 8.20 g. in weight. Test fish were exposed to various concentrations of the two materials at a ratio of 1.8 g. of fish per litre of solution. Fish used in the experiments were acclimated to and tested at 10°C.

One-half (23 litres) of the total volume of each test container was exchanged daily to minimize the possible diminution in DDT content by loss to the test fish. Daily determinations of DDT content were made by withdrawing one litre of each test solution and extracting the DDT with isopropyl ether. Such samples were taken at the beginning of each experiment, and immediately before each 23 litre solution exchange.

Results

Toxicity of Atlox 2082A to coho salmon underyearlings

Samples of 10 fish were exposed to each of eight concentration levels of Atlox 2082A from 500 p.p.m. to 10 p.p.m., along with a control. Times to 50 per cent

Table I

Time to 50 per cent sample mortality (ET_{50}) for samples of 10 coho underyearlings exposed to various concentrations of Atlox 2082A in fresh water.

Concentration of Atlox 2082A, p.p.m.	ET_{50}, minutes
500	33
100	98
70	290
50	380
40	680
30	1,125
20	2,450
10	>12,517
Control	No mortality

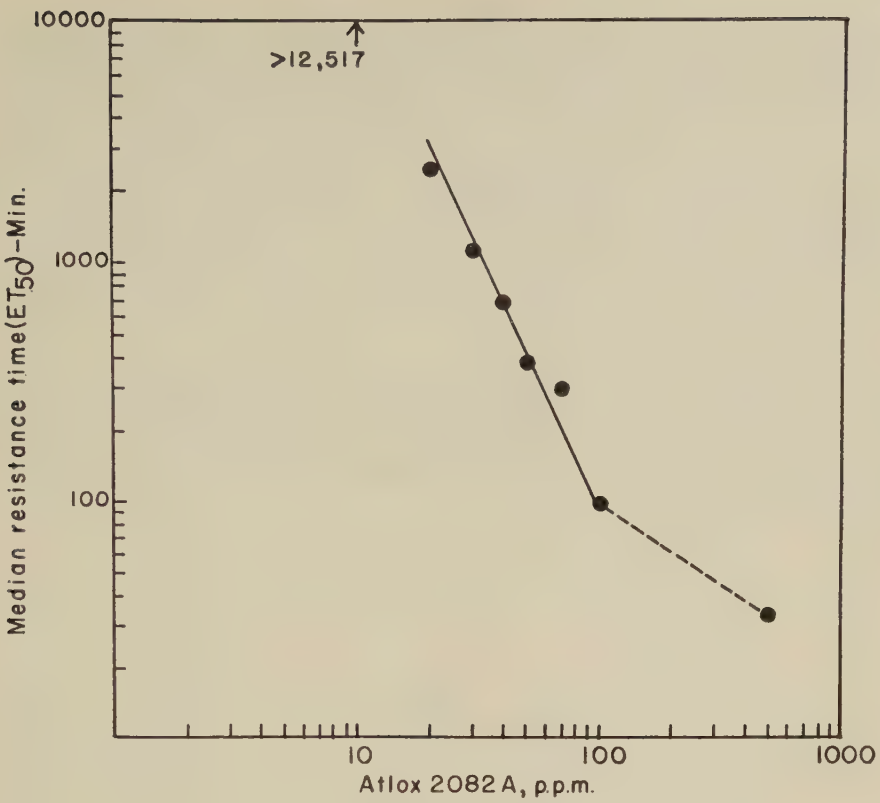

FIGURE 1—*Times to 50 per cent mortality in samples of 10 underyearling coho exposed to various concentrations of Atlox 2082A. The arrow in the upper corner refers to a test at 10 p.p.m. which was discontinued at 12,517 minutes.*

mortality in each concentration were calculated from the distribution of mortality times. Results of the tests are listed in Table I and illustrated in Figure 1.

Analysis of the transformed data provides an equation for the line from 20 to 70 p.p.m. From the equation the 48 hr. TL_m (median tolerance limit) (see Doudoroff, et al 1951) may be inferred and is estimated as 20.7 p.p.m. of Atlox 2082A. A safe level of Atlox 2082A, in terms of the experimental procedure, is estimated as 0.1 x 48 hr. TL_m or 2.1 p.p.m. Atlox 2082A. On the basis of the aerial spray formulation a unit of the spray in water containing 1 p.p.m. of DDT would contain about 0.15 p.p.m. of Atlox 2082A. Therefore, the concentration of DDT in a unit of water containing 2.1 p.p.m. Atlox 2082A would be approximately 14.0 p.p.m. DDT.

Toxicity of Aerial Spray Formulation to Coho Salmon Underyearlings

Samples of 10 fish were exposed to each of six concentration levels of the aerial spray formulation in water. The formulation does not form a stable emulsion in water and partition of the oil and aqueous layers occurred very rapidly. It was assumed for this reason that only a limited amount of the theoretical doses of DDT applied would be available throughout the water mass. In the higher concentrations tested a film of oil was visible on the water surface of the test containers. Subsequent tests also

indicated a considerable amount of the DDT in the test tanks was being adsorbed upon sediment in the freshwater supply and precipitated with that sediment to the bottom of the tanks. The latter fact has been well documented in the literature (see Berck, 1953). For these reasons the remaining concentrations established for tolerance tests are reported both as theoretical doses (level of DDT concentration by volume dilution) and as actual doses (level of DDT by chemical analysis of water taken midway between the surface and bottom of the test containers). Results of the tests on the aerial spray formulation are listed in Table II. Probit response curves for the concentrations examined are illustrated in Figure 2. The ET_{50} values derived from these curves are illustrated in Figure 3.

The median resistance times describe a most unusual response distribution. Maximum response in terms of time to death occurs at a dilution of the spray formulation providing a theoretical dosage of 0.5 p.p.m. (actual dosage of 0.05 p.p.m.). Test fish were less susceptible to the solutions at dosages both less and greater than 0.05 p.p.m. DDT (actual dosage).

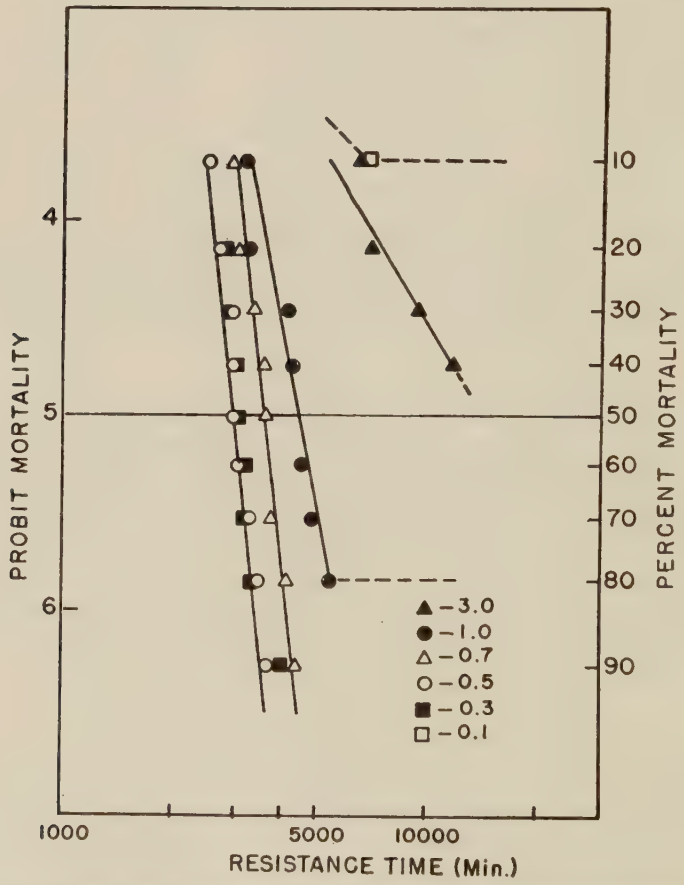

FIGURE 2—*Probit response curves illustrating the rates of mortality of coho underyearlings exposed to various concentrations of the aerial spray formulation. The curves are identified as to the theoretical concentrations of DDT applied, in p.p.m.*

Table II

Time to 50 per cent mortality (ET_{50}) for samples of 10 coho salmon underyearlings exposed to various concentrations of the aerial spray formulation.

Dilutions of aerial spray formulation providing DDT at the following theoretical concentrations, p.p.m.	Average concentration of DDT by chemical analysis, p.p.m.	ET_{50}, minutes
3.0	0.36	>12,492
1.0	0.19	4,400
0.7	0.11	3,600
0.5	0.05	2,950
0.3	0.10	2,950
0.1	0.07	>14,459
0.03	0.02	>10,031
Control	Control	No mortality

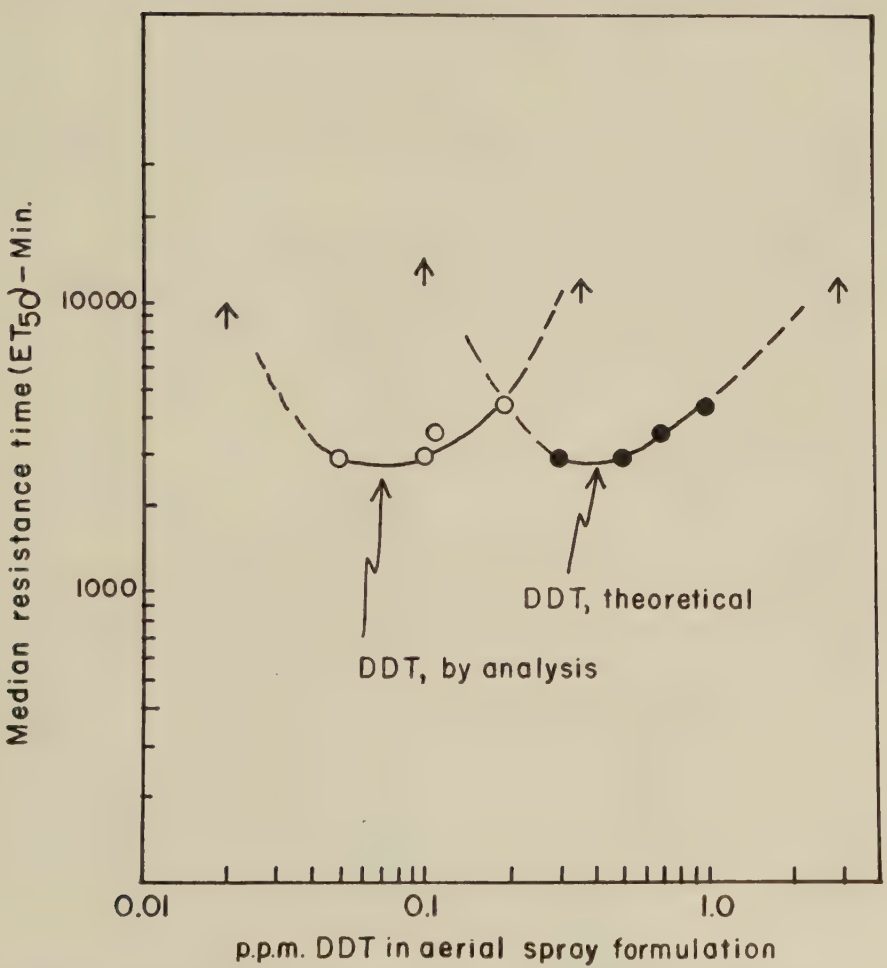

FIGURE 3—*Times to 50 per cent mortality in samples of 10 underyearling coho exposed to various concentrations of the aerial spray formulation. The arrows refer to tests in which 50 per cent mortality had not occurred at the times when the tests were discontinued.*

A further observation made in the 3.0 p.p.m. theoretical concentration (0.36 p.p.m. by analysis) supports field evidence of the Department of Fisheries (private communication). After 11,000 minutes of exposure almost all fish still living showed symptoms of blindness. Quite evident was the opacity of the lens of one or both eyes of these remaining fish.

Toxicity of DDT-Acetone Standard

Samples of 10 fish were exposed to each of six concentrations of a DDT-acetone standard. Although a highly stable emulsion was produced by the mixture of these materials, there was a tendency for the DDT to crystallize out onto the surface of the water solution, apparently on evaporation of the acetone carrier. Again it was suspected that DDT would be adsorbed onto particulate matter in the water, with a resulting diminution in the amount of DDT available throughout the water mass. Results of this series of tests are listed in Table III. The distribution of median resistance times is illustrated in Figure 4.

Table III

Time to 50 per cent mortality (ET_{50}) for samples of coho salmon underyearlings exposed to various concentrations of the DDT-acetone standard.

Dilutions of the reference solution providing DDT at the following theoretical concentrations p.p.m.	Average concentration of DDT by chemical analysis, p.p.m.	ET_{50}, minutes
3.0	0.31	850
1.0	0.29	730
0.7	0.06	850
0.5	0.05	1,100
0.3	0.09	1,150
0.1	0.08	1,750
0.07	0.05	>10,075
Control	Control	No mortality

In this series nearly all test fish died within the first 48 hours, consequently few analyses were possible for actual DDT content of each test solution. Some of the error in the response distribution for this series is undoubtedly connected with inability to sample at shorter intervals. A further source of error would be associated with variations in the amount of particulate matter in the test solutions.

Analysis of the transformed data indicates considerable variation in the distribution of resistance times; nevertheless, the trend in median resistance times is considered to be linear (Figure 3). Abrupt changes in slope within the probit response curves from 0.1 to 0.7 p.p.m. DDT theoretical dosage suggested that the response of the fish to the solutions might have been changing with evaporation of the acetone carrier.

Interpretation of Results

A limiting concentration of Atlox 2082A is estimated to be approximately 2.1 p.p.m. and, proportionately, this amount would be found at a DDT level of 14.0 p.p.m. The action of Atlox 2082A as a toxic agent would probably be found only at

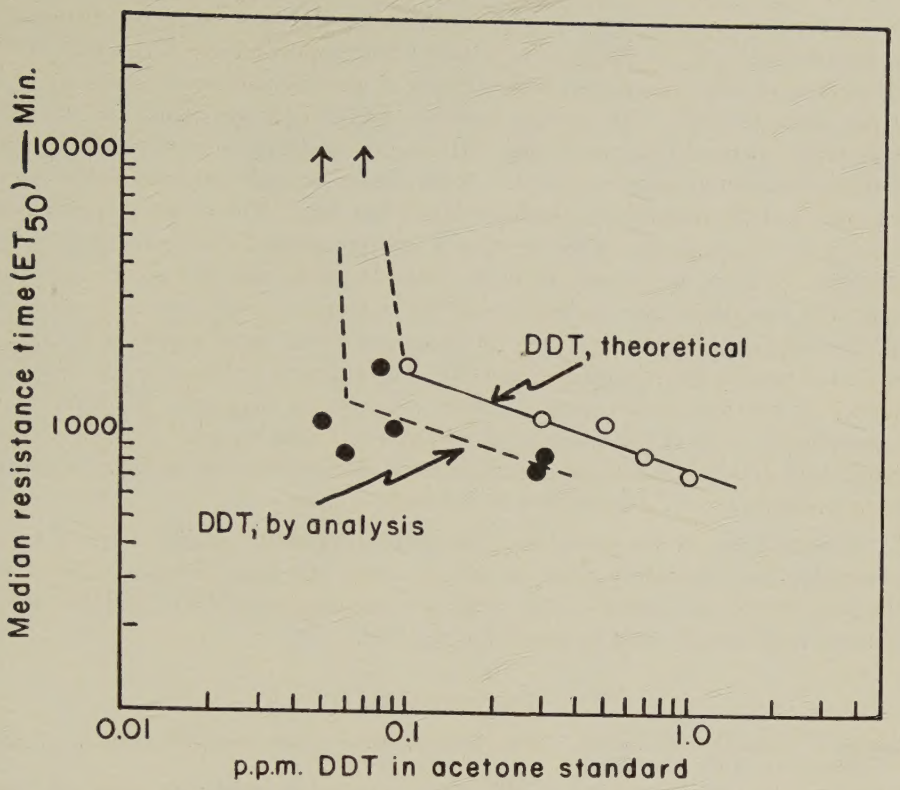

FIGURE 4—*Times to 50 per cent mortality in samples of 10 underyearling coho exposed to various concentrations of the DDT-acetone standard. For an explanation of the arrows, see Fig. 3.*

extremely high concentrations of spray formulation. It is doubtful if such concentrations would be found under spray conditions.

No valid statistical comparison can be made between the response distributions for the aerial spray formulation and DDT-acetone standard as that of the former is not linear. The bizarre distribution of resistance times for the aerial spray formulation suggests that the physical aspects of contact with the spray formulation or its components are dissimilar within the range of concentrations examined. In terms of DDT available in the water mass, the aerial spray caused mortality at and above 0.05 p.p.m. whereas 0.02 p.p.m. available DDT did not affect the test fish within the experimental period. In the case of the DDT-acetone standard, the lowest concentration producing mortality was again 0.05 p.p.m. available DDT. However, as the 0.07 p.p.m. test (0.05 p.p.m. available DDT) did not cause mortality within the experimental period, whereas the 0.5 p.p.m. (0.05 p.p.m. available DDT) did, factors may operate to determine toxicity other than that of the final amount of DDT available. Comparing the two response distributions from another aspect, the resistance times of the samples of young salmon exposed to the aerial spray are greater than those for the fish exposed to the same range of DDT concentrations in the DDT-acetone standard, even though this range ultimately was lethal in both cases.

In summary, and in terms of the test conditions, the aerial spray formulation may be regarded as "safe" to young coho salmon below approximately 0.05 p.p.m. where the measure of safety is regarded as the absence of mortality within an exposure period of one week at 10°C. An unusual response distribution was found for the aerial spray with resistance times increasing with increase in dosage over the higher portion of the concentration range examined. Associated with high concentration of spray, however, was development of blindness in the test fish. The series of tests tended to point up the complexity of the problem of interpretation of the action of associated variables. Besides the measure of DDT available to the test fish within the water mass, it is considered that the stability of the solution in such aspects as volatility, gravity stability, adsorptive potential of inclusions in the water supply and action of associated formulation components may have a considerable influence on the biological activity of the formulation used. Indeed, such factors may to a large extent be responsible for some of the diversity of tolerance estimates reported in the literature. A thorough study of the relation of such physical characteristics to biological effects on fishes would be a useful adjunct to such tolerance studies.

It should also be recognized that the criterion of safety applied here for young salmon does not necessarily relate to the impact on the total biological community. The tests do indicate, however, the range of concentrations of DDT and the related exposure times which could be harmful in the field.

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